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Energy Research and Development in the USSR

Energy Research and Development in the USSR

Preparations for the Twenty-First Century

William J. Kelly, Hugh L. Shaffer, and J. Kenneth Thompson

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Preface

This book discusses energy research and development (R&D) efforts under way in the Soviet Union and attempts to provide the reader with an understanding of the major technical, economic, geographic, and social factors that are motivating or, at least, influencing Soviet R&D activities in the energy area. The discussion is organized around seven basic goals that we believe are implicit, if not always explicit, in the formulation of current Soviet energy policy:

Increase nuclear electrification.
Raise crude oil production.
Increase the output of Arctic gas.
Make greater use of Siberian coal.
Increase the efficiency of energy utilization.
Introduce alternate energy technologies to meet local needs.
Achieve an optimum mix of energy sources to meet evolving national requirements.

This volume was written with a number of audiences in mind. One audience is the Western scientific community, and for its benefit we have included a large volume of scientific and technical (S&T) material on the substance of research and development initiatives in the Soviet Union. Our purpose, however, has not been to produce a technical treatise that would educate researchers on the technical details of Soviet R&D activities. Instead, we have sought to provide enough technical information so that our S&T audience can gauge the level and directions of Soviet work in a particular field. This technical material is supplemented with bibliographic references and sufficient information on key personalities and organizations (e.g., appendix E) to enable the interested technical reader to begin a more thorough review of Soviet activities on his own, using materials available in English and Russian. A second audience that we have envisioned consists of Sovietologists and other analysts of international affairs in the intelligence community and in academic centers of the Western world. With this group in mind, we have endeavored to keep the scientific discussions to a level where they should be understandable to the educated layman and have tried to include enough material on the geographic, industrial, economic, and political context of Soviet energy R&D so that analysts specializing in fields other than science and technology will be able to relate this work to their particular fields of expertise.

Beyond those two major groups of readers, we believe this volume contains material that should interest students of the history of science, administrators of R&D, experts on the problems of bureaucracy, social scientists, and the inquiring layman.

The volume can best be termed interdisciplinary, reflecting the half-dozen academic degrees of the authors (in economics, mechanical engineering, and Russian) and over half a century of collective experience in academia, government, and the private sector. As such, it is the culmination of a number of past activities, including personal research conducted in various academic settings, contract research performed for the federal government (the Office of Technology Assessment, Lawrence Livermore Laboratories, and other units), and research supported by the Battelle Columbus Division. Related research has been reported at annual meetings of the Southern, Western, and Midwest economics associations and has been published in journals such as *Soviet Studies*, *The Journal of Economic History*, and *The Journal of European Economic History* and in various reports to the federal government.

Of the other works in this field, this volume is most closely related to Robert W. Campbell's *Soviet Energy Technologies: Planning, Policy, Research and Development* (Indiana University Press, 1980). The two works are somewhat competitive in that both discuss the state of the art in Soviet energy technologies. However, they can better be described as complementary because of their numerous differences in coverage and in orientation. In the area of oil and gas, for example, Campbell limits his discussion to a few technologies that are examined in a technology transfer context (imported pipe, compressors for pipelines, and submersible electric pumps), referring the reader to his earlier volumes on oil and gas technology. By contrast, we do not deal with compressors and submersible pumps but do discuss geochemical prospecting, drilling technology, enhanced recovery of crude oil, offshore technology, and a variety of R&D initiatives relating to pipelines (e.g., efforts to develop a laminated pipeline for gas transport).

Campbell traces the historical development of energy technologies and often makes detailed comparisons between the current state of the art in the USSR and the United States. Our treatment looks to the future, rather than to the past, and is more focused on the individuals and organizations involved in current efforts and the substance of their work. Campbell asks why the Soviets are where they are today; we ask where they will be tomorrow.

A final difference of our study is that it is more oriented to the scientific community because of its greater emphasis on R&D personalities and organizations and on the content of R&D. Campbell, on the other hand, is more oriented toward the historian and Sovietologist.

The reader wishing to learn more about Soviet energy is urged to read Campbell's studies, as well as several other excellent works that are available in English: Leslie Dienes and Theodore Shabad, *The Soviet Energy System* (V. H. Winston & Sons, 1979), and Central Intelligence Agency, *USSR Energy Atlas* (1985). The last two works are particularly helpful on geographical aspects of Soviet energy.

This enterprise has been a collective effort to a considerable extent, with two or more authors working on various chapters or sections of chapters over the years. Nevertheless, primary responsibility can be distinguished in most cases, and the table of contents has been annotated to reflect this.

Like all authors of this sort of book, we have had to decide when to cut off the effort. In general, we have not attempted to incorporate materials published after the end of 1984. Soon after this book is published, the Eleventh Five-Year Plan will be history and the Twelfth Five-Year Plan (1986–90) will be under way. We are not especially uneasy about this because, in six years of working on this manuscript, we have noted few discontinuities in this field. The Soviet Union now has a large stock of institutes, researchers, and projects in energy R&D. It no longer is possible to add dramatically to this total or, given the ponderous nature of the Soviet bureaucracy, to change directions quickly. Obviously, change is occurring and will continue as the years pass. But many of the underlying trends of the Soviet energy system and the R&D establishment itself seem likely to evolve rather than to experience revolutionary change. Therefore, while we expect the annual totals and many details to change over time, we believe that the reader will find in this work much information and many truths about Soviet energy R&D efforts that will have lasting value.

Acknowledgments

The authors wish to express their appreciation to a number of individuals who have provided assistance in the course of this effort. First and foremost, we wish to acknowledge our intellectual debt to Russell Bowen and Ralph Rostron who have provided valuable suggestions on the content and general shape of the study and have offered their encouragement and advice over a period of years. We also wish to express our gratitude to Timothy P. Spengler, who has contributed generously of his ideas and provided written materials that were important inputs to the discussions of nuclear electrification, UHV power transmission, and oil shale. Lloyd Armstead read the entire manuscript and offered valuable advice on numerous points. Others offering comments included Saleh Abou-Zied (nuclear electrification), Donald Anson (boiler R&D), Satya Chauhan (coal conversion), Edward W. Collings (superconducting power transmission), Philip Izrailovich (energy modeling), Stephen Millett (Party organs), Mason Soule (energy modeling), Warren Swenson (nuclear electrification), Jack Terry (nuclear electrification), David Warner (electricity), John Young (R&D management), and two anonymous referees for Duke University Press. Charles Higgins has called our attention to numerous articles published in Soviet newspapers.

Encouragement and moral support have been provided by the management of Battelle, including Ben Freudenreich, Gus Simpson, Jr., Bruce Davis, David Judy, Douglas Hill, and Frederick J. Milford. Without the support of these individuals and the financial assistance provided by Battelle at their request, this study would not have been possible.

We are indebted to Betty Pierpoint and others of Battelle's Text Processing Services for their substantial and much appreciated edito-

rial and secretarial assistance, and to Jennifer Patton of Battelle's Technical Illustration Department for her assistance in creating the graphic figures.

Last, but by no means least, we wish to thank the women in our lives who have assisted in this effort by listening patiently to hundreds of hours of our ramblings on these subjects, by counciling forbearance when we became exasperated with one another, and by encouraging us not to be stopped by the many impediments that all authors encounter in such enterprises.

The authors accept responsibility for any errors that remain.

Chapter 1 Introduction

Background

Production and consumption of energy in the Soviet Union have been of increasing interest to Western analysts over the past decade for a number of reasons. Since energy source materials are an important input to the production of most goods and services used in the Soviet Union, future Soviet economic growth possibilities are closely related to the supplies of these materials.* The USSR also is of interest because of its current role and possible future role in world energy markets. The Soviet Union is now the world's largest producer of crude oil, the world's second largest producer and consumer of energy source materials in general, and a major exporter of energy. However, recent inability to prevent declines in the annual rate of crude oil production may jeopardize the USSR's ability to generate foreign exchange by selling oil on the world market and to cover the energy needs of its East European allies. (Soviet oil production growth rates were as follows: 1976—6 percent, 1978—5 percent, 1980—3 percent, and since 1981—1 percent or less. In 1984 production of crude oil and condensate totaled 613 million metric tons (m.t.), down 0.5 percent from 1983(2, 3, 4, 5). The firing of the minister of the oil industry (Nikolai A. Maltsev) in February 1985 is one of a number of signs of leadership concern about the Soviet energy situation, in general, and the crude oil situation, in particular(6).

In spite of its autarkic tendencies, the USSR has been subject to many of the same energy-related pressures that have affected Western nations. Production of crude oil generally has increased and has remained well ahead of domestic consumption, but attractive world prices of crude have awakened Soviet planners to the high opportunity costs of consuming oil at home rather than exporting it. This situation, plus recognition of the finite nature of fossil fuel supplies in the long run, has heightened Soviet interest in a whole series of activities aimed at making petroleum available for export while ensuring the short- and long-run availability to the Soviet economy of a suitable mix of energy sources. Taken together, those activities amount to a significant national energy program that, over the next two decades, could absorb around 20 percent of overall investment in the economy(7).

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*A 1978 study found correlation coefficients of 0.98 to 0.99 between energy consumption and various measures of aggregate production in the Soviet Union(1). (Numbers in parentheses refer to numbered references that can be found at the end of this book.)

Soviet energy efforts, like those of the United States, are based on several time horizons and range from actions that can be implemented in the near future to some that cannot be effective for many years.

Short-run efforts include attempts to increase energy production from traditional sources (e.g., existing coal mines and oil fields) and policies to improve the efficiency of energy utilization. Energy conservation activities can be found throughout the Soviet economy and have become a part of the national economic planning process. For example, these various conservation efforts were expected to result in total energy savings in 1980 of over 100 million metric tons of standard fuel (in comparison with 1975 norms) (8).

Medium-term initiatives are directed toward ensuring adequate supplies of fossil fuels over the next several decades. These include plans to step up the search for crude oil and natural gas resources in western Siberia, the Arctic, and offshore; efforts to enhance the rate of recovery of crude oil and natural gas by secondary and tertiary means; and research on new approaches to the recovery and transmission of energy from Siberia's plentiful reserves of coal.

In the long run, Soviet planners realize that fossil fuels will become increasingly expensive to recover and transport to the European part of the country as reserves are depleted. Accordingly, they have included in their plans a number of R&D efforts aimed at ensuring the availability of alternative sources of energy. Increasing amounts of electricity are to be produced over the next few decades by nuclear fission(8). In the more distant future the Soviets hope to obtain substantial amounts of electric power via the fast breeder reactor and nuclear fusion. Research also is being directed at the development of solar, wind, and geothermal energy sources; magnetohydrodynamic power generation; and cryogenic power transmission. Of course, not all of these options will prove to be both technically feasible and economically attractive. However, planners wish to determine which are, and to be ready to implement the best of the new technologies when new energy sources are needed.

Along with these initiatives, which are largely technical in nature, the Soviet Union has directed increased attention to economic aspects of energy. The planning of energy development and national fuel balances is, of course, nothing new in the Soviet Union. The famous GOELRO plan for the electrification of the Soviet Union during the 1920s was one of the first efforts at planned economic development in the Soviet Union. Since then, there has been a continuing concern with the role of energy in the development of the national economy. But interest in the problems of planning energy R&D, production, and consumption has intensified as oil and gas production has expanded in areas of the country that are remote, environmentally hostile, and expensive to develop. Soviet planners increasingly are preoccupied with problems such as the projection of future demand for energy (in the Soviet Union and abroad), the siting of power plants and other facilities that consume large quantities of energy, and the problem of choosing an optimal mix of energy sources. The emphasis on planning and economic calculation is natural, given the high capital investments involved in many energy projects, the long planning horizons required, and the substantial technical and economic risks associated with many projects. As in the United States, these considerations are further complicated by a growing sensitivity to environmental consequences.

In recognition of these dynamic economic problems, the All-Union Scientific Research Institute for Comprehensive Fuel and Energy Problems (VNIIKTEP) was created in 1974 to assist Gosplan USSR in handling a number of economic and planning problems associated with the development, transportation, and use of existing and new sources of energy. According to Director S. N. Yatrov, the new institute will play an important role in the coordination of Soviet R&D efforts related to energy(9).

As noted earlier, Western analysts are interested in the Soviet energy situation because of the importance of energy as an input to the Soviet economy and because of the potential implications of Soviet energy production and consumption for world energy markets. The analysts would like to be able to predict Soviet production, consumption, and net exports of energy for at least a decade into the future. In order to do this they must, among other things, be able to predict which energy R&D alternatives the Soviets will pursue and how successful these efforts are likely to be.

Because the R&D choices that will be made and the probabilities of success depend on a number of factors, analysts can only hope to understand and predict Soviet actions and results if they closely study these conditioning factors. Official plans for the development of the Soviet economy are of obvious importance, as are the technical characteristics of the R&D initiatives themselves. In addition, one must consider a number of other factors likely to affect the decision-making and program implementation processes, including the technical capacities of the R&D facilities and individuals involved in the efforts; the economics of the competing energy activities; and the relationships and rivalries among individual institutes, ministries, and government organizations, and among their personnel.

Purpose and Nature of the Study

The purpose of this research effort was to assess the Soviet energy R&D establishment and its capacity to support the energy policies and programs associated with seven basic national goals. The research project called for the collection and organization of information on R&D programs, organizations, and personalities involved in Soviet energy R&D; characterization of the major programs directed at the seven target goals; analysis of relationships and rivalries among key personalities, organizations, and programs; and the description and assessment of Soviet energy strategy in the seven target areas.

The study has profited from a variety of original and secondary sources, including several studies prepared earlier by Battelle's Columbus Laboratories. Some of the program details reported here have been covered by other authors. While we have added considerably to this detailed knowledge base, we consider the principal contribution of this study to be the synthesis presented in chapter 9 and numerous evaluative judgments found throughout the book. Other chapters provide the necessary foundations and background for these judgments.

Scope of the Study

The study reported on here began as an initial effort to analyze Soviet national energy R&D strategy, rather than as a comprehensive investigation aimed at definitive answers. It has expanded considerably in the past six years, but there continue to be some limitations on the scope of the effort.

The Soviet Union has initiated a large number of energy-related R&D programs, ranging from massive commitments of resources for nuclear fusion to modest efforts to use low-temperature geothermal waters to heat greenhouses. In the course of our research, an attempt was made to compile a master list of energy-related R&D programs and associated facilities. However, this book focuses on a subset of programs—those that support one or more of the following seven basic goals of Soviet energy development:

(1)Increase nuclear electrification.
(2)Increase recovery of crude oil.
(3)Expand output of Arctic gas.
(4)Increase exploitation of Siberian coal.
(5)Increase the efficiency of energy utilization.
(6)Introduce alternate energy technologies to meet local needs.
(7)Achieve an optimum mix of energy sources to meet developing needs.

Even after narrowing down to these seven goals, one must contend with an unwieldy number of R&D initiatives. Specific programs were selected for one or more of the following reasons: (1) they seemed likely to have a substantial impact on Soviet production or consumption of energy by 1995;* (2) they seemed likely to absorb a significant portion of Soviet R&D resources; (3) they were addressed to a critical problem; or (4) they were of special interest for other reasons.

The balance of this book is organized as follows. Chapter 2 discusses the structure and behavior of the energy R&D section in the

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*Soviet energy modeler A. A. Makarov sees goals such as (1), (2), and (3), and other smaller measures accounting for over one-half the growth in Soviet energy production through the end of this century(10).

Soviet Union, with special attention given to the planning of energy R&D. Chapter 3 deals with efforts to expand the production of electricity from nuclear sources, including traditional thermal fission reactors, fast reactors, and fusion reactors. Chapter 4 discusses selected programs directed toward increasing the production of crude oil and Arctic gas; specific topics include geochemical prospecting, drilling technology, enhanced recovery of oil, offshore technology, and pipeline transport of Arctic natural gas. Chapter 5 is devoted to a complex of programs that should facilitate the exploitation of Siberian coal, including ones aimed at the surface gasification, liquefaction, and drying of coal; pipeline transport of coal; and conversion of coal to electricity. Chapter 6 discusses some of the many Soviet efforts to increase the efficiency of energy utilization. Special attention is devoted to magnetohydrodynamic (MHD) power generation, ultrahigh-voltage transmission of electricity, superconducting power transmission, and pumped-storage hydroelectric power generation. Chapter 7 considers programs dealing with nontraditional energy sources, most of which seem likely to be employed only in selected localities. Specific topics include underground gasification of coal, solar energy, wind power, geothermal energy, oil shale and peat, and hydrogen. The last of these is nontraditional, but not necessarily of limited geographical significance. Chapter 8 examines Soviet use of mathematical models for determining an optimum mix of energy sources. Finally, in chapter 9, an attempt is made to pull together what has been learned from examining Soviet R&D efforts in the energy area and to develop hypotheses about the future course of Soviet R&D in energy and the implications of this R&D for the production and consumption of energy in the Soviet Union over the next several decades. The organizing principle for these hypotheses is "rational" behavior on the part of the Soviet Union, as perceived by the authors of this volume. Deviations from the rational scenario for bureaucratic, military, or other reasons are considered. There also are six supporting appendixes, including one that provides formatted information on the most important R&D organizations (appendix E).

Chapter 2 R&D in the Energy Sector: Structure and Behavior

In this chapter we will present a brief introduction to the structure and behavior of the Soviet energy R&D system. We will focus on (1) the primary organizations involved with energy R&D and central planning and (2) decision-making. This emphasis is appropriate because of the prominence of these features in the technology-related chapters that follow (chapters 3–8). The third topic of this chapter —decentralized decision-making—has been included because an understanding of the Soviet economy requires a recognition of its "mixed" nature. No attempt is made to provide a comprehensive review of all aspects of the system; rather, the discussion is limited to those aspects that will be most helpful to the reader in understanding the references to such matters in the remainder of this study.

The discussion of the energy R&D system provided here is supplemented by chapter 8, which examines energy modeling—an important input to Soviet national economic forecasting—and by appendixes A, B, C, and D, which provide energy-related main directions of Soviet economic development in the Tenth (1976–80) and Eleventh (1981–85) Five-Year Plans, as well as a list of S&T councils associated with energy.

The Organizational Structure

Introduction

According to Academician N. P. Fedorenko, director of the Central Economic Mathematics Institute, the Soviet economic management system can be viewed as a system with four basic hierarchically arranged sets of organs: (1) policy-making organs, (2) central planning

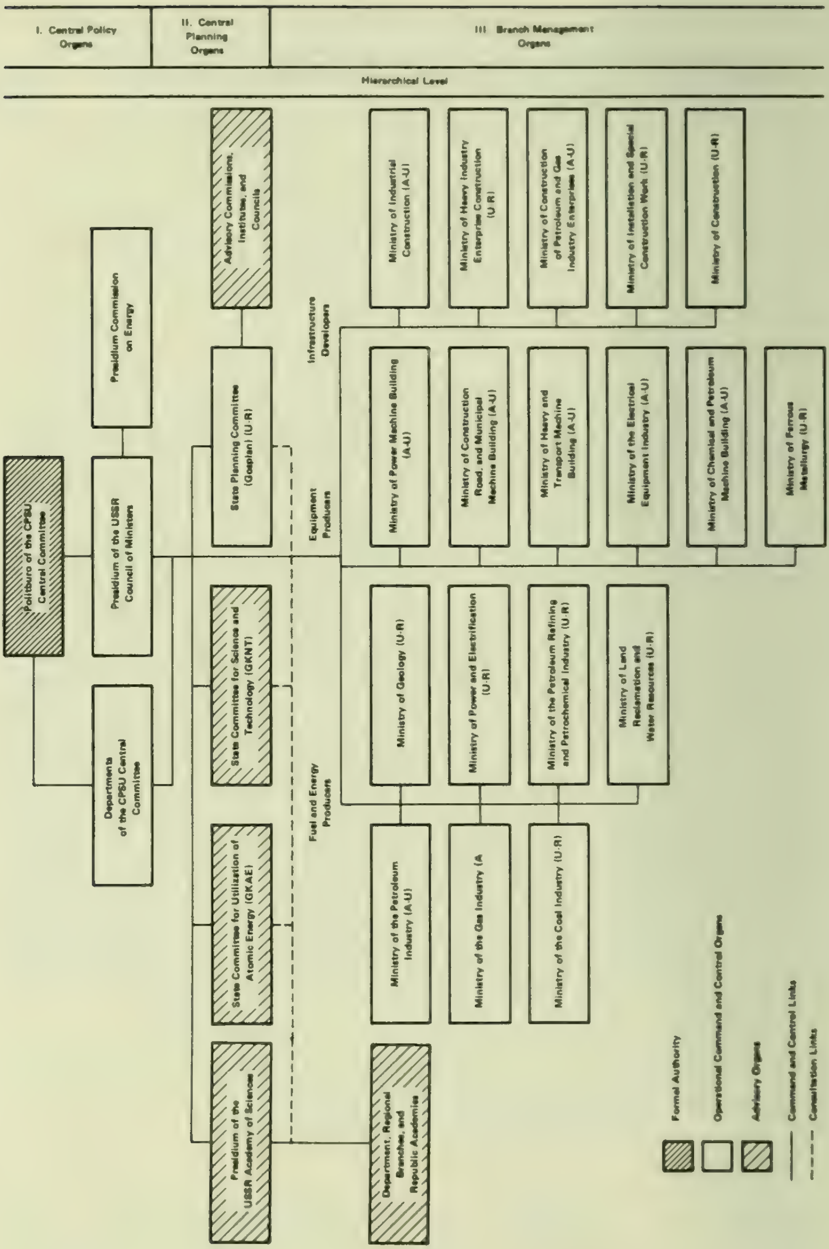
I. Central Policy Organs
II. Central Planning Organs
III. Branch Management Organs
Hierarchical Level
Politburo of the CPSU Central Committee
Presidium Commission on Energy
Presidium of the USSR Council of Ministers
Departments of the CPSU Central Committee
Advisory Commissions, Institutes, and Councils
State Planning Committee (Gosplan) (U-R)
State Committee for Science and Technology (GKNT)
State Committee for Utilization of Atomic Energy (GKAE)
Presidium of the USSR Academy of Sciences
Department, Regional Branches, and Republic Academies
Infrastructure Developers
Equipment Producers
Fuel and Energy Producers
Ministry of Industrial Construction (A-U)
Ministry of Heavy Industry Enterprise Construction (U-R)
Ministry of Construction of Petroleum and Gas Industry Enterprises (A-U)
Ministry of Installation and Special Construction Work (U-R)
Ministry of Construction (U-R)
Ministry of Power Machine Building (A-U)
Ministry of Construction Road, and Municipal Machine Building (A-U)
Ministry of Heavy and Transport Machine Building (A-U)
Ministry of the Electrical Equipment Industry (A-U)
Ministry of Chemical and Petroleum Machine Building (A-U)
Ministry of Ferrous Metallurgy (U-R)
Ministry of Geology (U-R)
Ministry of Power and Electrification (U-R)
Ministry of the Petroleum Refining and Petrochemical Industry (U-R)
Ministry of Land Reclamation and Water Resources (U-R)
Ministry of the Petroleum Industry (A-U)
Ministry of the Gas Industry (A
Ministry of the Coal Industry (U-R)
Formal Authority
Operational Command and Control Organs
Advisory Organs
Command and Control Links
Consultation Links

Figure 1 Organizational Structure of Soviet Energy R&D

organs, (3) branch planning and management organs, and (4) the organizations directly engaged in research, development, and production(1). Figure 1 depicts the first three levels of this scheme. (The fourth-level organizations occur at the central as well as at the branch levels and consequently are difficult to represent properly.) Figure 1 also represents the basic types of interactions among the elements of the system (formal authority, operational control, and coordination, including the provision of expert advice)(2). In the following material we will examine the organizational structure from the point of view of both Fedorenko's hierarchy and interactional patterns.

Policy-Making Organs

The formal organs that constitute the Soviet power structure are the central organs of the Communist Party of the Soviet Union (CPSU) (the Politburo and the Secretariat), the USSR Council of Ministers, and the USSR Supreme Soviet, with the latter two organs constituting the formal government of the USSR.* A substantial overlap between the Party and the government exists at the central level, reflecting the shadow power structure that underlies and unites the formal structure. Thus, the number of top Party and government offices is normally greater than the number of persons holding those offices. For example, both Leonid Brezhnev and Yuriy Andropov held the offices of General Secretary of the Central Committee of the CPSU (CC CPSU) and Chairman of the Presidium of the USSR Supreme Soviet, and each was probably the de facto chairman of the Politburo of the CC CPSU. N. A. Tikhonov, the chairman of the USSR Council of Ministers, was also a full member of the Politburo. We will limit the discussion to the formal structure, but it should be borne in mind that in the USSR the constitutional division of rights and responsi-

*The Supreme Soviet will not receive further treatment. It has neither operational control over the R&D and production facilities nor formal authority to set policy. The Supreme Soviet is an organ of "state" power. As such, it enacts legislation, accredits foreign diplomats, confers honorary and military titles, and exercises other formal functions of state. The Supreme Soviet maintains commissions for various sectors of the economy, including science and technology. These commissions serve as an additional forum for public discussion of plan development and control over plan implementation. Thus, in late 1983 the S&T commission heard a report on estimated economic benefits claimed for new technological developments. (The report found many instances of inflated claims[3].)

bilities among the formal organs is of much less importance than the unity of the shadow structure.

It is commonly held that, whereas the Party has both formal authority to decide policy and operational command over the government bureaucracies, the government has only operational control. Policy proposals, however, are developed by both the Party and the government. The government's competence in the areas of economic and R&D planning certainly exceeds that of the Party, and, therefore, it is probable that the Party is highly reliant on the government for advice in this regard. However, since the process of economic policy-making in the USSR is so highly politicized, Party decisions will be heavily influenced by the proposals of its own bureaucracy.

The Politburo. The Political Bureau (Politburo) of the CC CPSU is normally held to be the highest authority in the USSR. The Politburo, which normally has roughly twelve to fifteen full members and six candidate (nonvoting) members, alone has formal authority to decide national economic policy and to allocate resources to realize that policy. The individual members of the Politburo, however, rely heavily on the advice of scientists, economists, and managers in the government, including the USSR Academy of Sciences, when formulating policy in technically complex areas such as energy.*

The Secretariat. The Secretariat of the CC CPSU normally consists of nine to ten secretaries. It is headed by a general secretary who is also believed to be the ranking member of the Politburo. In recent years, roughly one-half of the secretaries of the CC CPSU also have been members of the Politburo. The Secretariat is the administrative organ of the Party. It approves all appointments to Party offices (with the probable exception of the Politburo), channels all communications between the Politburo and the rest of the Party, coordinates Party staff work, and initiates investigations into reported or suspected violations of Party rules.

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*Our only direct insight into Politburo energy policy is based upon public statements by individual Politburo members. A content analysis of economic statistics cited by individual Politburo members in the years 1971 to 1978 revealed a concern with energy issues by four members (Brezhnev, Kosygin, Kirilenko, and Kunayev) who accounted for about 90 percent of all energy references by the Politburo[4]. According to this study, Politburo attention to energy increased substantially during the 1970s: energy accounted for only 3 percent of total citations in 1973 but reached 12 percent by 1978. Politburo interest in coal was low between 1972 and 1976 (0.4–0.5 percent of all citations) but increased to 3 percent in 1977 and to nearly 6 percent in 1978. No time trend for natural gas was observed, and the citation of crude oil statistics was erratic. (Concern with the Arab oil embargo was evident in the 1974 citations.) Politburo concern with all forms of electricity generation, including nuclear, declined over the period covered (50 percent of energy citations in 1972 versus 19 percent in 1978). Politburo interest in energy is believed to have increased since 1978 or 1979, but no rigorous analysis has been made of the statements.

The Secretariat maintains about twenty departments that provide oversight over Party and government activities and provide the Politburo with expert advice and policy proposals. Energy production falls under the jurisdiction of the Heavy Industry Department, while energy R&D is under the Science and Educational Institutions Department. The former is known to maintain coal, petroleum, and geology sectors. These departments have a substantial degree of de facto operational control over the government either directly (through explicit directives to managers qua government officials) or indirectly through directives to managers qua Party members.

The USSR Council of Ministers. The USSR Council of Ministers consists of more than ninety top-level government administrators, including ministers, chairmen of state committees, and chairmen of the fifteen union-republic councils of ministers. The Council, in tandem with the Secretariat of the CC CPSU, exercises operational command over nearly all scientific, technical, and economic activity in the USSR. The Council alone, however, is responsible for the compilation of the state plans, including R&D plans, and for the financing of economic activity. It is probable that the Council rarely if ever meets in full session. The work of the Council is normally conducted by a Presidium (currently consisting of a chairman, three first deputy chairmen, and nine deputy chairmen). The deputy chairmen have responsibility for various economic sectors or services. Deputy Chairman A. K. Antonov, head of a CMEA commission on cooperation in the production of nuclear power station equipment(5), is believed to be responsible for the Soviet energy sector(6).

Several commissions under the Presidium have been formed in the Eleventh FYP period to handle the development and implementation of key economic and S&T programs. These include Presidium commissions for energy, fuel and materials conservation, and West Siberian oil and gas region development programs. The last-named commission works in tandem with an analogous commission under the State Planning Committee.

A little-publicized body, known only as the "Referentura," appears to be attached to the central apparatus of the USSR Council of Ministers(7). The functions of this body are unknown, but judging by its name it probably provides expert advice and research for Presidium members on request. The Referentura may provide support during energy policy deliberations within the Presidium or within the larger forum of the Council at large.

Central Planning Organs

The major functional agencies of the USSR Council of Ministers involved with energy R&D in the USSR are the State Planning Committee of the USSR (Gosplan), the State Committee for Science and Technology (GKNT), the State Committee for the Utilization of Atomic Energy (GKAE), and the USSR Academy of Sciences (AN SSSR). Gosplan, by virtue of the plan directives it issues in the name of the Council of Ministers, is an organ of operational command. The other three organs are advisory and provide expert advice and coordinate development of the R&D plans with Gosplan. By and large, the GKNT has no administrative control over the branch R&D and production organizations, but it does have considerable influence in the allocation of R&D budgets and in the approval of research programs. The GKAE and the Academy, on the other hand, maintain their own research institutions. In addition to its coordinating role, the Academy acts as a branch planning and management organ for a network of 244 research facilities in the natural and social sciences.

Gosplan. Gosplan has overall responsibility for the formation and integration of the economic, social, and R&D plans. These plans, which reflect the broad policy guidelines established by the Party, guide the ministries and other state agencies in their activities.

The members of the State Planning Committee proper include the committee chairman, the deputy chairmen, and the chairmen of the GKNT and of four other key state committees (prices, labor and social questions, construction, and supply). In addition, the finance minister, the head of the Central Statistical Administration of the USSR, and a vice president of the USSR Academy of Sciences are members of the Committee(8). Thus, Gosplan serves as a forum in which the heads of the major planning agencies can meet and negotiate a plan acceptable to everyone.

Gosplan is divided into departments (*otdely*) that are responsible for the various economic sectors or functional services. Related departments are grouped together as directorates (*upravleniya*), the most important of which is the Directorate for the Consolidated Planning of Economic and Social Development, which includes the Consolidated Department of Science and Technology. This directorate appears to handle Gosplan's work on the comprehensive S&T programs. Also of interest are the Directorate of Fuel and Energy Resources, the Directorate of the Raw Materials Branches [of the Economy], and the Consolidated Department for the Introduction of New Technology. The first of these contains departments for coal, oil and gas, and power and electrification.

Gosplan maintains a number of advisory organs that support the development of energy plans. The most important of these are the Council for the Study of Productive Forces, the Institute of Complex Transport Problems, the All-Union Scientific Research Institute of Comprehensive Fuel and Energy Problems (VNIIKTEP), and the State Experts Commission. VNIIKTEP, which was created in 1974, is responsible for forecasting energy production and consumption and is supported in this regard by the Academy's Siberian Power Engineering Institute in Irkutsk(9). (See chapter 8.) In this capacity, VNIIKTEP supports Gosplan's traditional role as the developer of national five-year and long-range forecasts. In addition, the institute directs or coordinates "a unified thrust in scientific research work in the area of the fuel and energy complex that is performed by branch and other institutes" and "coordinates scientific research work aimed at improving existing and developing new methods of using energy resources in the national economy"(9). In this latter function VNIIKTEP would appear to be encroaching upon the charter of the GKNT, which traditionally has had the responsibility for conducting a unified S&T policy in the USSR.

Finally, two Gosplan coordinating commissions involved in energy development have been identified: the Commission on West Siberian Oil and Gas Region Development, which is located in Tyumen and which parallels the aforementioned Council of Ministers commission, and the Interdepartmental Commission on the Use of

Renewable Energy Resources in the National Economy, which deals with wind, solar, and geothermal energy(10). The commissions were created to enhance Gosplan's "program" approach to planning.*

GKNT. The function of the GKNT is to "ensure the cohesion of state policy in the field of scientific and technical progress"(12). The GKNT, which was formed in 1965, is the "lead" applied R&D planning and coordination organ in the USSR. Although the GKNT has limited powers over the actual conduct of R&D, it performs important guidance and liaison functions for the various ministries and agencies in the area of R&D planning, coordination, and performance. The GKNT is chiefly concerned with a large, though limited, number of highly important R&D programs. It also handles contacts of Soviet scientists and engineers with foreigners, coordinates international cooperative programs, and approves requests for technology imports.

The GKNT maintains several departments involved with the development of energy technologies. These departments (and their known areas of activity) are the Department of Power and Electrical Engineering (generation and transmission of electrical power, renewable sources of energy, and energy conservation); the Department of Mineral Resources (mining technology and the development of coal resources); the Department of Chemistry (oil refining); the Department of Transport (pipeline technology); and the Oil and Gas Department (enhanced crude oil recovery).

The USSR Academy of Sciences. The USSR Academy of Sciences is the center of theoretical and experimental research in the physical, mathematical, and social sciences in the USSR. The fourteen republic academies of sciences (the Russian Republic does not have an academy) are operationally subordinate to both their respective republic councils of ministers and to the USSR Academy. The latter has control over their research programs, scholarly procedures, appointments to academy offices, elections to academy membership, and relations with the academies of the other CMEA nations. In addition, the academy monitors theoretical and experimental research in the university system and has some degree of control over the content of university research programs and the scholarly procedures employed.

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*Mymrikov and Mymrikova note that the structure of the state plan is conditioned heavily by the internal structure of the "planning organs" and by the organizational structure of the economy(11). A change in planning techniques, therefore, requires a change in both the internal structure of Gosplan, namely, the creation of program-oriented departments, and changes in the organizational structure of the economy.

The Presidium manages the Academy's daily affairs between sessions of the Academy's governing body, the General Assembly. The Presidium is headed by the president and vice presidents of the Academy and currently includes a number of leading scientists in energy-related fields, such as A. P. Aleksandrov (president), Yu. A. Ovchinnikov, and Ye. P. Velikhov in the area of nuclear energy and fusion; A. V. Sidorenko and A. A. Trofimuk in geology; I. A. Glebov in cryogenics; B. Ye. Paton in welding; and M. A. Styrikovich in magnetohydrodynamics and general power engineering. The Presidium is responsible for coordinating the national five-year plan for basic research with the GKNT and Gosplan. Funding for the Academy comes from the state budget, but the GKNT is believed to have the final word as to the size of its budget allocation and the content of its research program.

The Academy is responsible for forecasting trends in the economy, science, and technology in support of Gosplan's long-range planning efforts. The "Comprehensive Program for S&T Progress for Twenty Years" (see below) is developed jointly by the Academy and the GKNT; development of the new Energy Program was undertaken by Aleksandrov's permanent interdepartmental energy commission, which is jointly responsible to Gosplan, the GKNT, and the Academy(13, 14). Two Academy institutes—the Institute of High Temperatures and the Siberian Power Engineering Institute—are engaged in significant efforts in modeling and forecasting the development of the energy sector. (See chapter 8.)

Energy-related research in the Academy is centered in the Division of Physical-Technical Problems of Power Engineering, which is headed by Styrikovich. The well-known scientists in energy research in this division include N. A. Dollezhal (nuclear reactors), L. A. Melentyev (energy modeling), A. Ye. Sheyndlin (MHD and synthetic fuels), former first deputy chairman of the GKNT D. G. Zhimerin (power engineering), and Z. F. Chukhanov (coal enrichment). The division's major research activities include nuclear power engineering and controlled thermonuclear fusion (see chapter 3); the use of Kansk-Achinsk and Ekibastuz coal (chapter 5); pumped-storage hydroelectricity, magnetohydrodynamics, superconductivity, and UHV power transmission (chapter 6); and the hydrogen economy (chapter 7). The division also is active in the area of conventional power generation and development of high-power turbogenerators(15).

Other subdivisions of the Academy involved to some degree with energy include the Division of Nuclear Physics; the Division of Geology, Geophysics, and Geochemistry; the Siberian Division, which is headquartered in Novosibirsk; and the advisory Commission for the Study of Productive Forces and Natural Resources.

GKAE. The GKAE appears to be the major agency handling R&D in the field of civilian utilization of atomic energy. It maintains departments for accelerators, thermonuclear research and plasma physics, and a department (or administration) for atomic energy called Glavatomenergo. The GKAE, until recently, had administrative control over the Soviet Union's nuclear power stations, but control now has been transferred to the USSR Ministry of Power and Electrification(16).

Scientific (Problem) Councils. These councils are advisory organs, but ones that do not have an existence independent of the above-described organs. The GKNT and the Academy organize scientific problem councils to coordinate work on important interbranch problems included in the national five-year R&D plans. Councils under the joint jurisdiction of both the USSR Academy and the GKNT also are known to exist. The councils' recommendations carry considerable weight because of the personal prestige of the council members.

One of the most important councils is the USSR Academy's Scientific Council on the Complex Problem of Power Engineering, which comes under the Division of Physical-Technical Problems of Power Engineering. The council is known to have been in existence between 1975 and 1979 and was headed by Academician L. A. Melentyev. A Scientific Council for Interdisciplinary Energy Problems, also under the USSR Academy, was identified in 1981. This latter council may coexist with Melentyev's council or may have replaced it. The Siberian Division of the USSR Academy maintains a number of councils, the most notable of which is the Scientific Council on the Problem of the Comprehensive Assimilation of Natural Resources and Development of the Productive Forces of Siberia. This council, which was formed in 1979, is headed by Academician A. A. Trofimuk, the director of the Institute of Geology and Geophysics, and coordinates activities under the "Siberia" program(14).

Appendix D contains a list of the fifty-two energy-related councils we have been able to identify. The councils listed there cover the period from 1978 to 1983 and thus cover both the Tenth and Eleventh

FYP periods. Such a list is of interest largely because it sheds light on the specific problems included in these five-year plans.

Branch Planning and Management Organs

Branch planning and management organs are tasked with the operational control of broadly defined sectors of the economy or services. Two types of organs may be distinguished: the USSR Academy of Sciences and the industrial ministries. Since the Academy was discussed above, we need to deal only with the ministries here.

Soviet industry is organized on a branch concept, in which the activity of each branch of the economy (defined on the basis of goods produced) is managed by a ministry. The contemporary ministry system has developed over several decades of intricate changes wherein ministries have split and recombined in varying patterns. The number of central ministries and state committees has grown from under sixty in 1940 to over ninety in 1979, reflecting the rise of new industries and the tremendous growth in the size and complexity of individual ministries. Several hundred additional ministries are subordinate to the republic councils of ministers.

The ministries have become powerful political as well as economic interest groups that are only partially controllable by the central government. Groups of ministries lobby for state budgets that favor their interests. The defense-industrial ministries and the ministries that favor heavy industry are two such groups. (Khrushchev's ill-fated "Sovnarkhoz" reform of 1957 to 1965, which eliminated most of the central ministries, was in part designed to break the power of these bureaucracies.) The ministries also have considerable power to orient plan targets to their liking by presenting their capabilities and resources to their advantage. The content of the state plans reflects, to a substantial degree, the proposals pushed by the ministries themselves.

The primary energy sector ministries are listed in table 1. The primary fuel and energy production ministries include the ministries for coal, oil, and natural gas production, power and electrification, petroleum refining, and geology. The USSR Ministry of the Coal Industry is also responsible for oil shale and peat mining and for manufacture of underground coal mining equipment. The USSR Ministry of Power and Electrification also builds many of its power

Table 1 Primary Soviet Ministries Engaged in Energy Activities

Name of ministry, acronym, and ministry type	Areas of responsibility
A. *Primary fuel and energy producers*	
Ministry of the Oil Industry (Minnefteprom) (A-U)*	Extraction of crude oil and casinghead gas. It also has some responsibility for oil prospecting and exploratory drilling. Some responsibility for gas condensate extraction and processing.
Ministry of the Gas Industry (Mingazprom) (A-U)	Extraction of natural gas and gas condensate. The ministry is also responsible for all offshore oil and gas prospecting and extraction. Leading organ for geothermal energy production.
Ministry of the Coal Industry (Minugleprom) (U-R in Ukraine only)**	Coal mine design and construction, coal mining and enrichment. The ministry is also responsible for oil-shale and peat production and for the production of peat briquettes. In 1973 responsibility for the production of underground coal mining machinery and equipment was transferred to Minugleprom, probably from the Ministry of Heavy, Power, and Transport Machine Building. Coal conversion R&D.
Ministry of Geology (Mingeo) (U-R)	Exploration for minerals, fossil fuels, and geothermal resources. R&D on new prospecting techniques.
Ministry of Power and Electrification (Minenergo) (U-R)	Construction and operation of fossil-fuel fired electrical power stations, including cogeneration plants, hydroelectric power stations, and nuclear power stations. Also responsible for the construction and maintenance of the power transmission grid and the heat supply systems originating at cogeneration plants. R&D on coal conversion and pipeline transport of coal.
Ministry of the Petroleum Refining and Petrochem-	Petroleum refining, petrochemical processing, production of chemical

Table 1 (continued)

Name of ministry, acronym, and ministry type	Areas of responsibility
icals Industry (Minneftekhimprom) (U-R)	reagents for enhanced oil recovery, and production of fuels, lubricants, and synthetic rubber.
Ministry of Land Reclamation and Water Resources (Minvodkhoz) (U-R)	Assists in the construction of hydroelectric power plants and oil and gas pipelines, development and production of wind-power equipment.
B. *Equipment Suppliers*	
Ministry of Power Machine Building (Minenergomash) (A-U)	Development and production of the major pieces of equipment for electrical power generation, including boilers, turbines, and generators for hydroelectric, thermal, and nuclear power stations and auxiliary items for such equipment. The industry was a part of the USSR Ministry of Heavy, Power, and Transport Machine Building until 1975 when it was established as a separate ministry. The elevation of the industry to ministerial status is largely due to the priority accorded to nuclear electrification in the USSR. (Operates the "Atommash" PO in Volgodonsk and "Izhora" PO in Leningrad.)
Ministry of Construction, Road, and Municipal Machine Building (Minstroydormash) (A-U)	Production of construction excavators, graders, bulldozers, scrapers, and other products useful for mining and access operations.
Ministry of Heavy and Transport Machine Building (Mintyazhmash) (A-U)	Development and production of railroad locomotives and rolling stock, cranes, portable bridges, dragline excavators, and heavy power shovels, among other products.
Ministry of the Electrical Equipment Industry (Minelektrotekhprom) (A-U)	Production of electrical machines, electrical cables, illumination equipment, insulators and insulating materials, batteries, transformers, motors, electrical equipment for vehicles, and electri-

Table 1 (continued)

Name of ministry, acronym, and ministry type	Areas of responsibility
	cal welding equipment, among other products. Cryogenic, wind, and solar energy equipment development.
Ministry of Chemical and Petroleum Machine Building (Minkhimmash) (A-U)	Produces equipment for oil and gas extraction, including drilling equipment, and equipment for petroleum refining.
Ministry of Ferrous Metallurgy (Minchermet) (U-R in Ukraine only)	Produces cast iron and rolled steel products, including steel tube for pipelines, cold-resistant steel, and tubing for compressor stations.
C. *Infrastructure Developers*	
Ministry of Industrial Construction (Minpromstroy) (U-R)	Organized into twelve territorial main administrations encompassing almost forty-five autonomous republics, *krays*, and oblasts of the RSFSR. Subordinate organizations construct facilities for the chemical, petrochemical, and petroleum refining industries.
Ministry of Construction of Heavy Industry Enterprises (Mintyazhstroy) (U-R)	Organized into eight territorial main administrations covering more than twenty-five autonomous republics, krays, and oblasts of the RSFSR. These areas include the heaviest concentrations of enterprises in the mining, metallurgical, and coal industries.
Ministry of Construction of Oil and Gas Industry Enterprises (Minneftegazstroy) (A-U)	Builds gas and oil pipelines, processing plants, and some parts of petroleum refineries and service facilities. Constructs oil and gas pipeline compressor stations.
Ministry of Installation and Special Construction Work (Minmontazhspetsstroy) (U-R)	Operates as a subcontractor to other ministries, installing equipment, electrical apparatus, sanitary-technical facilities, control and measurement instruments, means of automation, and complex facilities.

Table 1 (continued)

Name of ministry, acronym, and ministry type	Areas of responsibility
Ministry of Construction (Minstroy) (A-U)	Assists in the construction of coal mines.

*A-U: All-Union (ministry exists only at national level).
**U-R: Union republic (ministry exists at national level and in one or more union republics).

stations and the power transmission system. In general, however, the development of the infrastructure (pipelines, railroads, etc.) is handled by a set of independent construction ministries. Much of the capital equipment used by the energy producers is supplied by a third set of ministries that produce turbines, nuclear reactors, excavators, draglines, drill bits, steel tubes, electrical cables, motors, batteries, welding equipment, trucks, construction equipment, and a host of other items.

The R&D Performers

The five principal types of R&D performing organizations in the USSR are (1) the academy institute, (2) the industrial institute, (3) the independent design bureau, (4) the higher school, and (5) the factory-based R&D facility. A sixth form—the association—represents the merger of two or more of the above types.

Academy Institutes. In 1976, the last year for which we have data, the USSR Academy of Sciences operated 244 facilities in various fields of research. Professional employment in the Academy in 1982 was roughly 49,500 persons(17). The Ukrainian Academy of Sciences operated seventy-seven research facilities in 1979(18); its total employment in 1982 was roughly 13,900 professional employees(17). The 13 remaining republic academies (the Russian Soviet Federated Socialist Republic [RSFSR] has no academy) are less important to the national R&D effort and are much smaller than the Ukrainian academy. The thirteen republic academies maintained a combined total of 317 scientific establishments at the end of 1975, or an average of twenty-four establishments each(19), and employed over 36,567 scientific workers at the end of 1982, or only about 2,810 per republic(17).

Industrial Institutes. The scientific research institute (*nauchnoissledovatelskiy institut*—NII) of the industrial ministries concentrates on the performance of applied research in support of new product or process development. In 1974 there were roughly 2,137 industrial NIIs in the USSR, including branches and external subdivisions (estimated as the reported total of 2,773 institutes minus 636 academy institutes)(20). Many large NIIs also are capable of performing basic research and design work. "Complex" NIIs perform a combination of applied research and design work; such institutes often carry the term "project-design" (*proyektno-konstruktorskiy*) in their names. In the ministries we have studied the NIIs are administered by either a "technical administration" that is responsible for R&D policy within the ministry, or have been merged with plants to create production or science-production associations (see below). Some ministries have extensive networks of R&D facilities. The USSR Ministry of the Oil Industry, for example, contained thirty-two specialized and regional institutes in 1979(21).

Design Bureaus. Design bureaus (*konstruktorskiye byuro*) (KB) are essentially engineering firms that translate applied research results into new products or processes. Many types of KBs exist, reflecting the wide variety of functions they undertake. The major independent KBs in the machine-building industries can produce prototypes as well as the blueprints for them. A KB with such manufacturing capabilities is known as an OKB (*opytno-konstruktorskoye byuro*) or test design bureau.

Higher Schools. The USSR Ministry of Higher and Specialized Secondary Education (MVSSO) and its republic-level counterpart ministries hold the preeminent position in Soviet higher education. The all-union MVSSO not only administers the various institutes and universities subordinate to it, but also controls the educational programs and the quality of instruction of the educational facilities of all other ministries and state agencies. Universities and engineering schools in the USSR, as in the United States, perform the double functions of training people and conducting research. The importance of higher school research in the USSR, however, is not as great as it is in the United States. In the mid-1970s, for example, Soviet higher school R&D accounted for only 4 to 6 percent of national R&D, compared with 10 percent for the United States in 1977(22, 23). The relative unimportance of higher school R&D is reflected in the general absence of such R&D in the discussions contained in the present work.

The Science-Production Association. Science-production associations (NPOS), consisting of a headquarters NII or KB with subordinate manufacturing and innovation-assisting facilities, began to be created in the early 1960s on an experimental basis. The R&D reform legislation issued in 1968 (see below) called for the diffusion of this organizational form throughout industry. By mid-1983, there were over 250 NPOS in existence(24).

The NPO is designed to promote the timely performance of R&D and to ensure its rapid introduction into production. It was hoped that the unification of research, design, innovation, and production under one management would cut lead times for the introduction of new technology. G. I. Marchuk, the head of the GKNT, claims that many NPOS have cut their lead times by 30 to 50 percent(24). The identity of NPO "corporate" management with the management of the lead NII or KB is intended to ensure the priority of innovation over routine production activities. R&D facilities of production plants, however, all too often are forced to concentrate on short-term production problems, thereby abandoning significant innovation work. In some NPOS, for example, R&D expenditures are reported to account for no more than 15 percent of total expenditures(25). Moreover, one hears complaints in the Soviet press that the constituent organizations are united in name only, with little corporate control over the subsidiaries, or that the ministries have levied standard output targets on the experimental plants, thereby inhibiting innovative activities.

Production Associations. In production associations (POS) a plant rather than an NII or KB is the lead facility. The PO is now the basic production unit in industry and is becoming quite common. The formation of POS nationwide was called for in the 1968 decree, and the 1979 decree on planning (see below) called for the completion of the process by 1982(26). However, by the end of 1982, POS (and NPOS) accounted for only about one-half of total industrial output(17). POS are underrepresented in this study partly because their activities are concentrated in areas lying beyond R&D, but mainly because their development work is not well publicized in the available Soviet technical literature.

Factory R&D. Most factories in the USSR, including those in associations, maintain some level of R&D capability, but the orientation has been toward solving day-to-day production problems, debugging new machinery supplied by other factories, or correcting the designs of new technologies developed by outside NIIS or KBS. A very few of the largest plants, however, such as ZIL in Moscow or "Uralmash" in Sverdlovsk, have large applied research institutes(27). Factory R&D accounts for a relatively small share of national R&D. M. L. Bashin estimated that factory-based R&D accounted for about 14 to 15 percent of total expenditures on "science" (*nauka*) in the early 1970s(28). Plant-based R&D facilities accounted for only 12 to 13 percent of the total scientists and engineers employed in industry in 1980 and were spread over some 1,500 to 2,000 plants; the average plant laboratory or design bureau was staffed by five to ten people in some machine building sectors(29).

Comments

The institutional structure of the Soviet R&D establishment exhibits a number of characteristic features that distinguish it sharply from those found in the countries of the industrialized West. The Western reader who wishes to understand the behavior of the Soviet R&D establishment should be cognizant of these differences. Three general features that are often ascribed to the Soviet system by both Soviet and Western analysts warrant comment at this point.

First, Soviet R&D is conducted within a highly centralized, bureaucratic system of state-owned facilities. The present R&D system is part of a more general but analogous system of economic management that was created under Stalin at the beginning of the 1930s. Control over the activities of the R&D performers has been by means of bureaucratic or administrative mechanisms—largely by means of plan assignments—rather than economic mechanisms. Centralization, state ownership, and administrative levers maximize state and Party control over the R&D sector in accordance with Party ideology, but also reflect a distrust of economic mechanisms, a lack of understanding of the operation of economic forces in unplanned economies, and a reluctance to relinquish active control over any significant economic process.

Despite leadership misgivings over any substantial decontrol of the economic management system, it is becoming clear to Soviet academic economists that this centralized, bureaucratic system is becoming increasingly ineffective in dealing with an economy in which dynamic technological change is a fundamental requirement to offset diminishing marginal returns to the factors of production. According to Berliner, the leadership may be forced to consider some change in the system if Soviet GNP growth continues to weaken or turn negative, but the changes he foresees could range from a re-Stalinization of the economy (heightened centralization, stricter social discipline, increased reliance on the police, among other features) to some form of liberalization (withdrawal of planning to the "commanding heights," with some mixture of state and private ownership)(30). Berliner believes that any bold move in the direction of liberalization would most likely have to be preceded by a severe drop in confidence in the economy and in its managers by the population, while moves in the opposite direction are more ideologically palatable to the Party and perhaps to substantial portions of the populace who feel that "things have gone to pot since Stalin"(31).

A second feature of the Soviet R&D establishment is its highly fragmented nature. Two forms of fragmentation may be mentioned: the division of the economy into ministries, and the division of ministries into institutes for research, KBs for design, and plants for production. The branch divisions facilitate central plan formulation and implementation, but hinder the diffusion of new technology and the organization of effective R&D programs involving cooperation between ministries. The intraministry divisions facilitate planning and division of labor and simplify management, but hinder the flow of new technology from concept to productive use. The fragmentations within the industrial system and their harmful effects on technological progress have been the subject of several important reforms in the past fifteen years. In 1968 the government embarked on a program of converting industrial plants and R&D facilities into associations that, in the case of science-production associations, would include applied research, development, and production plants under one management. The objective was to unite the goals of the disparate facilities making up the association and thereby speed up the assimilation of new technology. Plans to create analogous associations involving facilities from more than one ministry, however, appear to have come to naught.

The prospects for continued expansion of the use of the association form are uncertain. Although the press comments regarding the NPO and PO forms have been generally favorable, it is clear that true unity of the subsidiary units has not always been achieved, in part because of the reluctance of plant managers to relinquish their independence and authority. In addition, the association enhances a tendency in the USSR to create overly large organizations. At least one Soviet writer has mentioned that the facility size mix in the industrialized Western countries has a much larger share of small- to medium-sized facilities than the USSR has(32). Finally, the association movement is a form of centralization (from the point of view of the plant or institute manager) and, as such, represents a move in a direction of questionable merit.

The third feature of the Soviet R&D establishment is its strong vertical organization and relatively weak horizontal relationships. The organization of the system as a whole may be compared to a pyramid with a large base of institutes, design bureaus, plants, etc., grouped into a much smaller number of ministries located halfway up the pyramid. The heads of the various all-union ministries and state committees constitute the apex of the state pyramid—the USSR Council of Ministers. Similarly, the individual ministry itself reflects this general structure of the economy. The productive units of a ministry are grouped under a small number of main administrations or all-union industrial associations differentiated by activity or product line. The apex of the ministry is the collegium, headed by the minister.

The hierarchical structure of the Soviet system facilitates the planning and management of a strongly centralized economy. The vertical nature of the institutional structure, however, strengthens the forces of departmentalism that act to inhibit effective cooperation between enterprises, institutes, and ministries, and encourages autarky or self-sufficiency with regard to the supply of as many productive inputs as possible. The autarky of the industrial ministries is growing, as evidenced by the rising share of "non-profile" products in total ministry output(33). In some product lines—plastics, for example—specialized ministries accounted for only 32 percent of total production in the early 1980s(33). Autarky, therefore, breaks down the "branch principle" of organizing the economy and weakens the national division of labor, leading to greater inefficiencies.

Another problem of the vertical orientation is the transfer of much decision-making from the enterprise level to the main administration, ministry, or central levels. The result is a considerable loss of flexibility and a complication of the lines of communication, with attendant losses in the accuracy and timeliness of information flows. Reforms to reduce the number of hierarchical levels within the ministry (to two or three levels) by the formation of associations have helped, according to Soviet sources, but the ministries have been slow in revising their internal structures. Since 1973, when the shift to two- and three-link management structures began, only seventeen out of ninety-four ministries at the all-union and republic levels surveyed in a recent Soviet study have complied(34). According to Gertrude Schroeder, the reforms to increase the strength of horizontal (e.g., plant to plant) relationships, such as the contract and cost accounting (*khozraschet*) reforms, have been largely ineffective(35).

Central Decision-Making: Plans and Programs

Introduction

R&D, like industry, agriculture, and other basic sectors of the Soviet economy, is subject to central Party and government direction. As indicated above, the Party has ultimate authority to determine R&D policy, while it is the responsibility of the USSR Council of Ministers and its agencies—primarily Gosplan, the GKNT, and the Academy—to develop concrete and coherent plans to implement this policy. The plan itself is, therefore, the mechanism by which the Party's policy decisions are communicated to the R&D performers.

The state plan, rather than price as in market economies, is the basic resource allocation mechanism in the USSR. R&D performers are given assignments to perform specific projects and are allocated specific financial, labor, and material resources to accomplish these tasks. The opportunities for conducting significant volumes of discretionary R&D are limited in order to concentrate resources on projects contained in the central plan.

The central planners have made serious attempts to include R&D in national economic planning only since 1965. Up through the 1950s, R&D was not given concentrated attention because Soviet economic growth could be achieved through extensive growth strategies wherein the quantity rather than the quality of productive inputs was the key. Heavy reliance was placed upon the use of foreign technology, either directly through imports or indirectly through reverse engineering by NIIS and KBS. Since the late 1950s, however, the continuously declining rates of Soviet economic growth have borne witness to the diminishing marginal returns to newly added factors of production(31). Although the need to offset these declines through increases in productivity was recognized, Khrushchev's dismantling of the ministry system in 1957 prevented the development of a coherent national approach to technological progress until the restoration of the ministries by Brezhnev and Kosygin in 1965. The R&D planning mechanisms that evolved thereafter were codified in a government decree issued in 1968. This decree called for an extension of the time horizon of the basic R&D plan from one to five years and the integration of the R&D plan with other sections of the economic plan. Long-range S&T forecasts were introduced as a means of selecting "main directions" of economic development (see below). A system of "coordination plans" also was introduced. Actually used for the first time before the reform was issued, coordination plans called for a more integrated approach to R&D projects by covering all stages of work from basic and applied research to final introduction into productive use(36). Other key features of the decree were the formal adoption of the association form for uniting R&D and production under a single management structure and the expansion of decentralized decision-making at the level of the R&D organization.

Parts of the 1968 decree have been superseded by a series of modifications culminating in a 1979 decree entitled "On Improving Planning and Strengthening the Influence of the Economic Mechanism on Increasing the Effectiveness of Production and the Quality of Work" issued jointly by the Party and the government(37). This decree, which is based, in part, on the much-publicized economic experiments within Minelektrotekhprom (see table 1) during the late 1960s and 1970s(38), included the following key features(35):

The three main planning documents are to be (1) the twenty-year comprehensive program of S&T progress; (2) the "main directions" (*osnovnyye napravleniya*) of economic development for five and ten years; and (3) the five-year plan (in place of the annual plan).

Changes in the plan indicator and incentive systems, notably the replacement of gross value of output by normative net output (average value added).

An enhanced role for program and regional planning.

Transfer of all economic entities, including NIIs and KBs, to complete self-financing.

The 1979 decree has been followed by over eighty additional instructions and another major decree issued in July 1981 concerning energy and conservation of raw materials(35). Strictly speaking, the decree is not a "reform" since the old system is retained in all its essentials; it is, in fact, being referred to by the Soviets as an "improvement in the economic mechanism." The intent of the decree according to Berliner was to squeeze a few more drops of efficiency out of the old system by enhancing the power of the central planners and extending the comprehensiveness of the plans. In his opinion, however, the system had probably already reached its peak efficiency before 1979, and further moves to improve the operation of the economy by increased centralization and more comprehensive planning were likely to be futile(30).

The Comprehensive Program of S&T Progress

Development of the five-year plans is preceded by an elaborate "preplanning" stage in which S&T, economic, and social forecasts are developed. Forecasts of the "most important S&T problems" form the basis of the "Comprehensive Program of S&T Progress for Twenty Years"(8). Forecasts are part of the planning system, but are not themselves plans(36). They represent the best judgment of experts as to the future course of the economy or probable developments in specific technical fields over periods of from five to as many as forty years into the future.

Development of the forecasts is handled by the USSR Academy of Sciences, with the assistance of the GKNT, Gosplan, and, in the area of construction and construction materials, the USSR State Construction Committee (Gosstroy)(8). Forecasts of the development of the energy sector are handled largely by the Academy.

The comprehensive program identifies tentative trends in the development of S&T, the rates and level of actual application of the achievements of S&T, the possible level of technical development of the economy at the end of the program period, and the allocation of resources to the various thrusts of technical progress(8). The current program covers the period from 1981 to the year 2000. An updated program covering the period between 1986 and 2005 was under development in early 1983(39).

Main Directions of Economic and Social Development

Main directions are statements of intended courses of activity and range from broad generalities to branch output targets. The main directions cover all economic activities, not merely S&T, and contain preliminary targets of the rates and scale of economic development in the aggregate and for individual sectors for the first five years of the period covered and qualitative limit indicators for the remaining years of the period covered. The "main directions" also specify goals for technical and industrial modernization for the economy as a whole, for individual branches, and for the various union republics. The main directions contain a section for the development of science and technology, including goals for the natural sciences. Based on the "Comprehensive Program of S&T Progress," Gosplan develops draft "Main Directions of Economic and Social Development of the USSR for 10–15 years," subdivided by five-year plan periods(8).

The draft main directions for the Eleventh FYP (1981–85) were examined and approved with some modification by the Central Committee and the Twenty-sixth Congress of the Communist Party and were designated "Main Directions of Economic and Social Development of the USSR in 1981–1985 and for the Period up to 1990." Examples of energy-related main directions for the Eleventh FYP include the development of territorial-production complexes at the Kansk-Achinsk and Ekibastuz Coal Basins and the West Siberian oil and gas region, significant growth in production of equipment for nuclear and thermal-electric power stations, and expansion of nuclear electrification. The complete sets of energy-related "main directions" for the Tenth and Eleventh FYPS are given in appendixes A and B, respectively.

The State Five-Year Plan

Content of the Plan. The formal plans include the state five-year plan and the annual plans derived from it. Both types of plans are hierarchical, ranging from the aggregate national plan down to the operational plans of enterprises, institutes, and design bureaus. Separate plans for R&D, industry, agriculture, investment, foreign trade, and other economic and social activities are developed and integrated by Gosplan in cooperation with other agencies and ministries. Once developed, the five-year plans are enacted into law by the USSR Supreme Soviet, and their assignments become legally binding upon the various institutions and individuals that compose the state-controlled sector of the economy.

Since 1979 the five-year plan has been the basic plan, at least in law, supplanting the annual plan in this role. The goals of the five-year plan are to be immutable, with no downward revisions permitted to adjust the long-range goals to the actual annual performance as in previous periods. It seems highly improbable, however, that the former practices can be so easily put to rest. (Coal production, for example, cannot be increased sufficiently in 1985 to reach the FYP target of 775 million m.t., and some downward revision of coal consumption therefore will be required.)

The R&D Plan. An R&D chapter—known as the "Plan for Development of Science and Technology"—has been included in the state five-year plan since the Eighth FYP (1966–70). The R&D plan currently contains the following eleven subchapters(40):

S&T programs.
Planning the assimilation of the production of new types of indusrial products.
Planning the introduction of progressive technology, mechanization, and automation of industrial processes.
Planning the purchase and sale of licenses and their use in the national economy.
Planning standardization.
Planning the scientific organization of labor.
Planning the basic indicators of the technical level of production and the most important types of industrial products.
Planning the economic effect of the introduction of S&T measures.
Financing S&T work.
Training scientists and science educators in graduate programs.
Planning foreign cooperative S&T tasks.

The R&D chapter is developed for Gosplan by the GKNT and the Academy. The ministries and agencies of the USSR and the union-republics develop derivative five-year and annual branch and republic R&D plans for their subordinate organs and organizations. These plans incorporate the tasks of the state R&D plan but are supplemented with branch or republic tasks. The R&D plan also includes the plans for research in the natural and social sciences developed by the Academy, with the approval of the GKNT for S&T and of Gosplan for economics(40).

Institute Plans. The operational plans of institutes (and probably KBS, as well)—the "project plans" or *"NIOKRpromfinplany"*—describe the actual R&D projects to be undertaken, their budgets, and schedules of completion. The institute plans also include targets for volumes of contract research, labor and wages, finance, incentives, and other operating considerations. Discretionary R&D projects, i.e., those projects initiated by the institute's director, also are included in the annual and five-year operational plans.

Program Planning

Program planning has been a part of Soviet central planning since the 1920s when the State Plan for the Electrification of Russia (GOELRO) was developed by Gleb Krzhizhanovskiy, but it has always had a minor role compared with the dominant sectoral planning, which is oriented toward planning economic activities by ministry. As noted above, sectoral planning has led to departmentalism, which has severely debilitated efforts to unite two or more ministries in the pursuit of some common goal. The dependence of modern technological development on interbranch efforts, however, has focused attention on the need to provide for such cooperation.

Beginning with the Eighth FYP (1966–70), Gosplan attempted to improve interbranch projects by the introduction of "coordination" plans. Deficiencies in coordination plans (weak management, poor integration of the stages of work, inadequate provision of financial backing) led to the adoption in the Tenth FYP (1976–80) of a new form—the S&T program—that was intended to be more comprehensive and better integrated than the coordination plans. The GKNT's authority to plan and supervise the S&T programs also was increased(41). The number of programs was reduced from 246 in the Eighth FYP to 240 in the Ninth FYP (1971–75) and to 200 in the Tenth FYP in order to better concentrate financial and managerial resources on projects of greatest priority(36). The next step, taken in 1979, was the move to comprehensive program planning. Subsets of these programs, known as target programs, are to be tied closely to the lines of economic and technical development derived from the long-range forecasts and are to have clearly expressed goals or "targets." Each program is to be realistically supplied with the needed labor, material, and financial resources.

Three major types of comprehensive target programs were included in the Eleventh FYP: economic, regional, and S&T. By January 1982 only some eleven to fifteen economic programs had been included in the FYP, but others may have been added since then(41). The economic target programs include the much-publicized Food Program, the Energy Program, and the Transport Development Program. Other economic programs appear to have been created to deal with energy and raw materials conservation, metallurgy, machine building, and the reduction of manual labor(8).

An important aspect of the new program approach is the increased emphasis on regional planning. The most important regional programs relate to the development of eight territorial-production complexes(TPKs), all but one of which is centered on the development of a major energy resource. The following TPKs are included in the Eleventh FYP(17) (investment figures are from reference [42]):

West Siberian TPK: based on the oil and gas resources of the North Tyumen region. Investment in the TPK for 1981 to 1985 is projected to be 50 billion rubles (see also chapter 4).

Timano-Pechora TPK: based on Arctic oil, gas, and coal resources. Investment in the Eleventh FYP is expected to be over 7 billion rubles.

South Yakutsk TPK: based on the coking coal basin at Neryungri. Total investment here is expected to reach US $16 billion (see also chapter 5).

South Tadzhik TPK: based on hydroelectric power resources.

Kansk-Achinsk Fuel and Energy Complex (KATEK) based on the lignite coal reserves of the Kansk-Achinsk Basin. The technologies being developed to supply the Urals and European USSR with energy from these coals are described in chapter 5. Investment in KATEK is expected to reach 6 to 7 billion rubles.

Pavlodar-Ekibastuz TPK: based on the sub-bituminous coals of the Ekibastuz Basin. Total investment in the TPK is expected to reach 8 billion rubles (see also chapter 5).
Sayan TPK: based on hydroelectric power resources.
Kursk Magnetic Anomaly TPK: based on iron ore resources.

The TPKS in 1982 accounted for 61 percent of crude oil, 51 percent of natural gas, and 20 percent of coal production nationally. In 1981 and again in 1982 the TPKS accounted for the USSR's entire increase in the production of these fuels(17).

All industrial and social development within the geographical boundaries of a TPK are to be administered by Gosplan without the need to coordinate decisions with the branch ministries(42). Gosplan has created a commission to handle the development of the West Siberian TPK and could create commissions for the other TPKS as well. The actual authority of such commissions is uncertain, but the branch ministries with plants and other facilities in these areas will exhibit strong resistance to any diminution of their control over them.

R&D projects of high national importance are being formed into S&T programs. The Eleventh FYP includes 170 S&T programs of two types. The most important programs—of which there are forty-one—are termed "comprehensive target S&T programs." The target programs are intended to result in the initiation of new product lines or the commissioning of new productive capacity. The second types of programs—of which there are 129—are called "Programs for the Solution of the Most Important S&T Problems"(40). The problems relate to the creation of new products, processes, and materials and their introduction into productive use, but also cover R&D in key technical areas that will result in innovation in a subsequent FYP.

The Eleventh FYP contains fourteen S&T programs related to power and electrical engineering (including four target programs) and nineteen programs related to the fuel industries and geology (including six target programs)(43). The weekly newspaper *Ekonomicheskaya gazeta* published reviews of some of these programs in 1983. The technical fields they involve are the following (*denotes a target program):

Large-diameter, laminated, high-pressure gas pipe* (headed by V. A. Dinkov, minister of the gas industry)(44).

Coal liquefaction, gasification, and pyrolysis*(45).
Surface coal mining machinery*(45).
Development of thermal-neutron and breeder reactors* (headed by Academy President A. P. Aleksandrov)(44).
New technologies for trunk pipeline transport, including pipeline container transport*(46).
New methods for increasing crude oil recovery to 55–60 percent*(47).
The unified electrical power distribution grid*(48).
New technologies for production of electrical and thermal energy, including large power stations burning low-grade coal*(49).
Solar and renewable energy sources(50).
Comprehensive study of the earth's crust by extremely deep wells to locate potential oil and gas resources(51).
New technologies for underground mining of coal in difficult geological strata(52).
New technologies for the efficient use of fuel, electricity, thermal energy, and waste heat in industry(53).
New technological processes and equipment to increase the depth of petroleum refining to 70 percent(54).
Production of high-quality mineral and synthetic fuel oils, lubricants, and lubricating coolant fluids(54).
New, highly effective equipment for hydroelectric and pump-storage hydroelectric stations(55).

Comments

Central planning defines the patterns by which the organizational entities discussed in the first section of this chapter interact with one another(56). The intention of the central planners is to create an arrangement of organs and interrelationships that acts to fulfill the economic goals established by the Party and to discourage behavior to the contrary. The essential interactional patterns of the Soviet economy are based on a system of controls (price control, supply planning, control over budgets and investment, state ownership of the means of production) that were created in the 1930s and that have remained intact despite a nearly continuous series of modifications or "reforms." Several features of this system should be noted.

First, the Soviet leadership generally has preferred a high degree of central control over the economy. The number of plan targets on which performance currently is to be judged is nearly as high as ever. The short-lived 1965 reform drastically reduced the number of such "success indicators" to six, but their number has increased since 1970 to around twenty. The "recentralization" may have been motivated by the leadership's concern that control was slipping away from them as the economy became more complex, but it was also motivated by the desire to limit the autonomy of institute and plant managers. Many Western analysts see this as a move in the wrong direction—the main problem of the Soviet economy has always been an excessive, not insufficient, degree of central directive control over the individual R&D and producer units. A highly centralized modern economy will lead to a greater burden on the planning bureaucracy and a greater diversion of national income to this nonproductive activity. D. Gvishiani, a deputy chairman of the GKNT, recently reported that the volume of data processing has increased by fifteen times in the past ten years, forcing a shift to computers merely to handle the flood of data(57).

Second, Soviet central planning tends to be comprehensive. The concern with comprehensiveness is related to the desire to extend planning to more and more forms of economic activity. The major addition to national planning since 1965 has been R&D. The 1968 reform of R&D planning called for the inclusion of basic S&T problems in the plan along with assignments for their solution, introduction of new technology into production, training scientists, and R&D financing, among other considerations. Comprehensive planning has led to problems with plan consistency or integration, where integration refers to the coordination of the tasks and resource demands of one plan section with those of the others. Plans often are developed that call for the performance of some specific activity but do not provide for needed equipment or materials or do not provide for the requisite financial resources. Coordination of the R&D plan was to be facilitated by the development of long-range forecasts that were to discover major trends and interrelationships in the economy and by the creation of programs encompassing the various stages of the research-to-production cycle.

Third, Soviet planning has always had a short time horizon, usually no longer than one year. The 1965 reform called for plans to be based on long-range forecasts, but the fundamental legal planning document was still the annual plan. Since 1979 the five-year plan has been designated the basic plan. The five-year plan is to be coordinated with the projections included in the ten-year "Main Directions" of the development of the economy and the "Complex Program of S&T Progress" (which now has been extended from fifteen to twenty years). The lengthened time horizons are intended to minimize changes in basic policy objectives and to tie the objectives to realistic long-term prospects for technological advance(30). The ability of the Soviet planners to realize this extended horizon in practice, however, may be beyond achievement since it is, in the final analysis, actual performance that will determine the feasibility of the five-year targets.

Finally, Soviet planning is essentially sectoral planning that has been increasingly burdened with "horizontal" forms of planning involving the coordination of the efforts of entities from a variety of ministries. Two forms of horizontal planning are now prominent—S&T programs and territorial production complexes. The rise of such planning at the expense of sectoral planning belies the inherent shortcomings of sectoral planning in an era of growth dependent on intensive, rather than extensive, factors, as well as the need to break down the parochial attitudes of the ministries that often result in the subordination of national to sectoral interests. Program and regional planning, however, may run afoul of the still-powerful sectoral organs (the ministries) and will add greatly to the work of the planners, with a resulting impairment of overall planning(41).

Decentralized Decision-Making: Incentives

The Soviet Mixed Economy

The Soviet economy, like other modern economies, is a mixed economy, one that contains elements of governmental control and market forces. The Soviet economy represents, perhaps, the extreme case of governmental control, but a substantial volume of decision-making in the USSR has not been (and so far cannot be) handled by the administrative mechanism of central planning. Decentralized management is grudgingly tolerated because the central government does not have the resources or technology to sufficiently develop comprehensive or consistent instructions to cover every conceivable situation that will arise during plan implementation. Lower-level managers in both R&D and production are, in fact, expected to react to plan deficiencies as a normal part of their responsibilities. (The latitude given the manager in this regard does not imply that the state is neutral to these decisions. All activities by NIIS, KBS, and plants should support the operational plan or the strategic objectives of the Party as reflected in the "main directions." In addition, institutes have "main directions" of their own [see appendix C] that should channel their project selection decisions in support of long-range research objectives.)

Since the creation of central planning in the early 1930s the economy has become increasingly mixed in nature. Central control has weakened as a result of the growing complexity of the economic structure due to the increases in the number of organizations in the economy, the expanded number and complexity of products, the growing importance of intensive rather than extensive use of resources, and the shift to interbranch rather than branch technology development programs. The Kosygin reform of 1965 for the first time officially recognized the legitimacy of economic levers, especially in promoting growth through technological progress(30). The reform sought to enhance decentralized decision-making by reducing the number of centrally imposed goals and by creating an incentive system that was intended to encourage economic efficiency in enterprise operations.

Although the reformers correctly identified the source of Soviet economic inefficiency—central directive planning—they apparently failed to realize the degree to which their reforms were inconsistent with the central planning system itself. The viability of the 1965 reform was weak because the system itself imposes a logical limit to decentralization. Unable politically to tolerate any decrease in central control over the economy, the Party and government began to chip away at the reform until, by 1979, the reform had been rescinded in all but name. (The Politburo itself appears to have been divided in its support of the 1965 reform[58]. A significant faction within the Politburo appears to have opposed the reform and to have provided support to ministers and plant managers who for parochial economic or political reasons opposed the extension of the reform to their bureaucracies. As a result, implementation of the reform has been slow: as of 1977, only ten ministries had been converted to the "new" system[39].)

Although the scope for decentralized decision-making in the Eleventh FYP has been substantially diminished, the R&D institute manager, as well as the enterprise manager, will continue to have a significant degree of freedom to determine (1) what concrete actions they will take in fulfillment of some specific task, e.g., selection of variants, (2) in what order of priority they will tackle their assigned tasks when fulfillment of all of them is not possible, and (3) what projects they will initiate with resources at their disposal but not devoted to fulfillment of plan assignments.

The volume of R&D conducted outside the central plan is significant. According to Ye. M. Karlik et al., the operational plans of NIIS and KBS in the mid-1970s contained by "volume" only 10 to 20 percent tasks assigned by Gosplan, while 20 to 30 percent represented tasks assigned to the ministry level. (Whether this is ruble volume or number of topics is not made clear.) The remainder consisted of contract R&D (30 to 60 percent) and discretionary, in-house R&D (about 10 percent)(59). The R&D facility manager, therefore, generally has substantial latitude in planning roughly one-half of the R&D conducted by his organization.

Several factors are relevant to an understanding of managerial decision-making, chief among which are incentives, prices, financial and salary systems, and accounting practices. For brevity, we will limit the discussion to the subject of incentives because of their effects on innovation.

Incentives

The central planners have attempted to unify their goals and the goals of the numerous production enterprises and R&D organizations by providing for monetary and other rewards for the successful achievement of plan objectives. In general, a basic bonus is granted for exact fulfillment of specific plan targets or a set of targets, and an adjustment is made for superior or inadequate performance. Thus, managerial behavior is conditioned by the nature and number of targets set before them and by the nature of the rewards for fulfilling them. The rules for forming and distributing these funds are complex and subject to continual modification. Such considerations lie beyond the scope of the present study and have been carefully analyzed elsewhere. The interested reader is referred to references (35), (60), and (61) for additional reading.

The current centrally imposed plan targets (success indicators) by which NII and KB performance is measured are set forth in a 1977 decree for NPOs and decrees issued in 1978 and 1982 for independent R&D facilities converted to the "new" system of planning, financing, and economic stimulation as defined in the 1968 reform(62). The principal success indicators for R&D facilities are (1) yearly economic effect (cost savings) derived from new developments; (2) average expenditures per employee for research financed internally; (3) fulfillment of the labor force plan; and (4) profit generated from contract R&D(63). The intention of the first of these is to orient the (applied) R&D performer to the development of economically beneficial products or processes as opposed to mere project completion or expenditure of budget allocations, as in NIIs and KBs not converted to the new system(64).*

Three incentive funds are created in R&D facilities that parallel the incentive funds found in industrial enterprises. The funds, known collectively as the Funds of Economic Stimulation, are the Fund of Material Encouragement, which is the source of bonuses paid to individuals for fulfillment of the success indicators; the Fund of Cultural-Social Measures and Housing, which supports the construction of apartments for employees, among other uses; and the Development Fund, which can be used to finance equipment purchases or decentralized investment in the organization. The funds are financed mainly through rebates on the profits earned by enterprises using the new technologies developed by the R&D facility(63). The size of the funds is determined by the central government in aggregate and by the respective ministry for individual NIIs and KBs and has some maximum size relative to profits and the other labor costs of the organization. The degree of actual target fulfillment can result in either increases or reductions in the size of the funds according to predetermined schedules.

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*Incentives play a minor role in the Academy. Since the economic value of basic research is difficult to assess, nonmonetary or "moral" incentives are more prevalent there.

In the mid-1970s profit was deducted into the incentive funds according to a sliding schedule of economic effects (savings) considered to result from the introduction of newly developed technologies, as follows(59):

Economic effects (thousand rubles)	Size of deduction (+ thousand rubles)	Range restrictions (thousand rubles)
Up to 10	14%	up to 1.4
10–20	12% + 0.2	1.4–2.6
20–50	8% + 1.0	2.6–5.0
100–500	3% + 5	8.0–20.0
500–2,000	2% + 10	20.0–50.0
Over 10,000	0.6% + 60	120.0 up to 200.0

Incentive deductions are limited to a fixed percentage of the economic effect. The declining rates for higher volumes of economic effect serve to limit the monetary gains of the developer. A maximum incentive award (R200,000) also is stipulated. In addition, incentive awards are divided among the organizations involved either according to some formula that reflects the planners' perceptions of the relative contribution of research, development, innovation, and production activities to technical progress, or according to the relative share of total wage expenditures contributed by each participating organization. Finally, 15 percent of the award is often transferred to the central ministry to augment special innovation incentive funds.

This arrangement weakens the R&D performer's interest in large-scale R&D projects because of their high cost and high risk and the prospect of only minor incentive rewards to offset them. Rather, the R&D performer is inclined to engage in a larger number of R&D projects with relatively small potential benefits to the national economy because by doing so he minimizes risk of project failure, while maximizing incentive awards.* Considerations such as these under-lie the perennial problem of Soviet R&D—the expenditure of resources on projects with low expected benefit to the national economy(64).

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*For example, the development of a new production process guaranteeing R20 million in economic effectiveness (Option A) qualifies the innovation team for a maximum bonus of R200,000. However, a project portfolio consisting of ten projects each guaranteeing an economic effectiveness of R500,000 (Option B) qualifies in the aggregate for the same R200,000 bonus, but the risk of failure is spread over a larger number of projects. Since Option B is as remunerative as Option A, but less risky, the R&D performer will prefer Option B. Gosplan, however, prefers Option A since it results in a net benefit to the national economy of R15 million over Option B.

The second type of limitation relates to Soviet insistence that the size of the bonus funds be related to the level of wage and salary expenditures. The former, according to many Soviet economists, should not be more than 30 percent of the latter(65). Bonus awards in excess of this limit, it is feared, will orient the enterprise (or NII) toward the special purpose activities for which bonuses are awarded, to the detriment of the basic goals, such as the volume and mix of output.

As a final limitation on incentive fund size we may mention the policy of minimizing intersectoral per capita incentive differentials. Simple application of the incentive rule relating awards to economic effectiveness has run afoul of the wide range of profitability rates in Soviet industry(63). Differentiated bonus fund-forming norms now are being applied to reduce these variations(66). The attempts to equalize bonus awards are in part motivated by a desire to eliminate a source of income inequalities, but also are aimed at preventing other undesirable consequences such as the unplanned movement of labor to the sectors offering higher wage packages.

A final dysfunctional feature of the current Soviet incentive system is the failure to unify the goals of the R&D and production components of the science-production complexes, such as NPOs and the larger POs. These new organizational forms are intended to bridge the departmental barriers between R&D and production that are rampant in the traditional system, but since the incentive systems have not been integrated, the organizational integration has remained in many instances a mere legality(67).

The Energy R&D Sector: An Assessment

The present study of Soviet energy R&D bears witness to a high level of technical achievement in the energy sector and an innovation record that compares favorably with that of the energy sectors of the industrialized Western nations. The innovative success of the Soviet energy sector derives from much the same factors that have contributed to technical progress in the defense sector: a high priority in resource allocation, close supervision by top-level Party and state officials, well-trained and equipped R&D cadres, and the existence of central development programs that act to concentrate resources and managerial attention on particular projects and to overcome the negative "systemic" effects inherent in the structure of the Soviet command economy.

Soviet technical achievements in energy are especially pronounced in electricity generation and transmission; coal mining, preparation, and combustion; and pipeline technology. Technical progress in the first two areas has long shown a high degree of independence from foreign technology, while dependence in the third is now close to being broken, owing to an intensive development program.

Since the construction of the world's first commercial nuclear power station in Obninsk in 1954 the Soviets have actively pursued the development of nuclear power technology. By 1982 they lagged behind only the United States and Japan in installed capacity and had another 80,000 MW of capacity under construction (see chapter 3). In addition, the Soviets have pursued the development of breeder technology and have two stations with breeder reactors in commercial operation, whereas the United States has abandoned its Clinch River breeder program before completion. The Soviets have a substantial fusion research program under way that has created several types of fusion reactors, including the Tokamak-type reactor, which was a Soviet innovation. The Soviets are pursuing the development of pressurized-water reactors as well as graphite-moderated, boiling-water reactors (BWRS), a line of development not currently being pursued in the West. The 1,500-MW BWRS developed in the USSR are the largest nuclear reactors in the world today. The Soviet Union has pursued the development of heat and electricity cogeneration, including nuclear cogeneration, on an unparalleled scale. Nuclear stations for the generation of heat alone also are under construction. Soviet hydroelectric turbines (not covered in this study) compare favorably with foreign models and have found markets in the West. In regard to power transmission, the ever-increasing distance over which electricity must be transmitted in the USSR has resulted in the construction of the world's highest voltage transmission lines. At present an 1,150-kV AC transmission line is under construction. (However, construction on a 1,500-kV DC line now appears to be halted.)

Significant efforts in coal mining technology (also not covered in this study) have been directed at coping with the difficult geological conditions in the deep mines in the Donets Basin (steeply dipping, very thin seams; tunneling in especially hard rock; and heightened requirements for safety technology). Soviet coal preparation R&D has resulted in several sophisticated coal preparation processes and the development of new reagents designed to handle specific types of Soviet coal (chapter 5). Large-scale boilers of indigenous design have been developed to handle low-grade coal from Kansk-Achinsk and Ekibastuz (chapter 5). Development of the 2,650-m.t.-of-steam-per-hour boiler for the especially difficult-to-burn Kansk-Achinsk coal is a significant technical achievement.

Finally, the recent developments in pipeline technology must be noted. Development of unique forms of laminated, large-diameter pipe for high-pressure gas pipelines, 25-MW and 16-MW gas-pumping units, and the "Sever" automated welding complex for 56-inch pipe (chapter 4) eventually will free the USSR of its import dependence in this area.

Despite its achievements, the energy sector has suffered from the innovation-inhibiting effects of the Soviet economic system, such as the failure (or inability) to allocate sufficient resources to the construction of key energy projects (the "Atommash" plant in Volgodonsk, the ETKh-175 coal pyrolysis facility in Krasnoyarsk, and the large electrical power stations in the Ekibastuz and Kansk-Achinsk Basins); supply problems (notably, again, the ETKh-175 facility) and the need to design around steel problems (operation of turbines at relatively low temperatures, development of the turbodrill because of brittle pipes, and the development of laminated pipe as a substitute for high-alloy pipe). Despite a growing awareness of the importance of innovation to future Soviet economic growth, the Soviets themselves admit that the rate of innovation in the economy is slowing. Not long ago it was reported that the share of new products in total output of the machine building sectors had fallen from 4.3 percent in 1970 to 2.5 percent by the end of 1980(68).

The causes of the poor Soviet innovation record, which have been studied in depth elsewhere (see references [12] and [69]), lie largely outside the scope of this study since they center on the industrial sector. The Soviet R&D sector, however, is often an unreliable supplier of new technology and is itself a cause of the poor innovative performance of Soviet industry. A few words on the subject are appropriate, therefore, since the ability of the Soviet R&D system to generate new technologies cannot affect Soviet economic performance if they cannot be applied in the manufacturing system. We will limit our comments here to those "systemic" features discussed in the preceding sections of this chapter: organizational structure, planning, and incentives.

Whatever advantages the organizational structure of Soviet R&D once held for the conduct of R&D (concentration of resources and minimization of redundant work), those advantages now have become severe disadvantages. It is, in fact, difficult to conceive of an organizational structure less congenial to innovation than the present Soviet system. First, the concentration of "scientists" in the universities and academy institutes and "engineers" in industrial applied research and design facilities enhances the natural tendency for fragmentation of scientists from engineers because of their divergent professional goals and social and academic backgrounds. Thus, the logical first step in the innovation process—the practical application of new knowledge—is severely inhibited. Second, the separation of R&D itself from production likewise inhibits the adoption of new technologies by plants because the plants often have too little control over the quality of the technology supplied to them by the R&D sector. Models of new machinery, for example, frequently need to be debugged by plant design engineers, require unavailable materials, such as special lubricants, or are not cost-effective to operate. Third, when inputs to the innovation process are to be supplied by organizations belonging to other ministries, the plant's reluctance to innovate is increased because it has even less control over these organizations than it does over an organization within its own bureaucracy. The only central state agency that attempts to coordinate interagency R&D projects —the GKNT—focuses its attention on a limited number of nationally important projects; most interagency transactions, therefore, occur outside of central supervision and control. A major consequence of the organizational structure, therefore, is a reluctance on the part of plant managers to engage in an activity, such as innovation, that requires a change in well-oiled supply relationships.

Central planning, as practiced in the USSR at least, has proven too inflexible to support rapid innovation. Long-term production and supply arrangements are fixed by the central government for thousands of products. Plan targets are set high enough to induce the plant manager to utilize all his available resources (which, Gosplan is always convinced, he has understated in order to provide himself with a safety margin) and to prevent them from engaging in unplanned activities. As a result, the plant manager struggles to meet his major target—output—and, consequently, tends to be disinterested in disruptive activities, such as innovation. G. Popov of the Moscow State University imeni Lomonosov even questions the feasibility of judging performance in terms of plan targets. "Imagine," he suggests, "that high jumpers are judged not on the height of their jump, but on the percent of fulfilling assignments made by their trainer. Yet, it is precisely height that is required for success at the Olympics"(70). In addition, with assurance that his output will be disposed of, the plant manager has a minimal interest in upgrading his product line or in being sensitive to the needs of his customers. In a market economy a producer behaving in this manner would soon lose his market, but business failure in the USSR is virtually unheard-of; market shares are the result of the planners' decisions, not the consumers'. The producer, therefore, is induced to satisfy his plan assignment at the expense, if necessary, of the consumer.

Finally, attempts to overcome these negative factors by means of monetary incentives have had limited effectiveness and, to a substantial degree, have been counterproductive. Incentives for the creation of new technology have been too meager to produce high levels of inventive behavior in the NIIs and KBs and have, in fact, encouraged the squandering of resources on projects with low economic benefit. Incentives for the plant manager to innovate also have been too small either to offset output bonuses lost during the period in which innovations take place or to offset the risks and costs of innovation caused by "systemic" factors, such as supply uncertainty, legal penalties for failure, bureaucratic inertia, and the general conservatism of plant managers with respect to innovation. Given Soviet antipathy toward income inequality, it is unlikely that incentive awards will be allowed to rise to a level sufficient to offset the risks involved.

Most Western analysts who have examined Soviet innovative behavior ascribe Soviet poor performance to factors such as resource availability (historical and social factors), resource allocation (political policy), and resource utilization (systemic effects)(27). The Soviet leadership, however, has tended to hold the system faultless, while laying blame at the feet of labor or management. The leadership's abiding faith in central directive planning, apparent in the 1979 decree on planning, has been reaffirmed in the major Party-government decrees, such as the decrees on strengthening labor discipline and on accelerating S&T progress, issued in the Andropov interregnum. The latest round of economic "improvements," which is being tested in the Ministry of Heavy and Transport Machine Building and the Ministry of the Electrical Equipment Industry, among others, offers little that was not tried in the now-defunct 1965 reform and little that stands a greater chance of being implemented on a national scale. One noteworthy feature of the new experiment is the resurrection of the Stalinist practice of denying bonuses to managers for nonfulfillment of major plan targets; in the present case, the target for volume of goods sold(71). Activities that threaten fulfillment of this target, such as innovation, which tends to disrupt output schedules, will once again be avoided with a vengeance. In this environment, the prospects for continued, if not increased, debilitation of Soviet technical efforts, including those in the energy sector, are as great as ever.

We now turn to a discussion of the energy R&D programs themselves.

Chapter 3 Nuclear Electrification

The Soviet Union has a large and ambitious program for expanding the use of nuclear energy, primarily in the generation of electricity. Progress has been slow to date, but the USSR could be entering a period of significantly more rapid growth. Soviet nuclear power stations (NPS's) generated 20.2 billion kwh of electricity in 1975, or 1.9 percent of total electricity(1). By 1980 the figures rose to 70.5 billion kwh, or 5.4 percent of overall generation(2), but missed the five-year plan goal for 1980 of 80.0 billion kwh(1). The Eleventh FYP (1981–85) goals for nuclear power call for the commissioning of 24,000–25,000 MW of additional nuclear capacity and an increase in electricity generation to 220–225 billion kwh, or 14 percent of all Soviet power generation (see appendix B, item 1.a.). Longer-range plans call for increasing nuclear's share to an ambitious 40 percent by the year 2000(3).

This chapter deals with the Soviet Union's programs in conventional fission reactors, breeder reactors, and thermonuclear fusion. Some brief information on the historical development of the nuclear power industry also is provided.

The Fission Reactor Program

Background

Despite its pioneering efforts in this field (the first Soviet commercial NPS was commissioned in 1954), the USSR has been slow in expanding its generating capacity, often falling substantially behind its own goals. Nuclear capacity in 1978 stood at 9,088 MW and rose

Portions of this chapter were prepared by Timothy P. Spengler.

to 16,230 MW by the beginning of 1982(4, 5). Capacity as of June 1, 1985, is estimated to be 25,390 MW as shown in table 2. (Approximate locations of operating NPS's are shown in figure 2.) In 1983, roughly 80,000 MW of new capacity was under construction at 18 NPS's, including four NPS's that already had one or more operational reactors(8).

A comprehensive S&T program for reactor development was created during the Eleventh Five-Year Plan. The program is headed by A. P. Aleksandrov, the president of the USSR Academy of Sciences and the director of the Institute of Atomic Energy imeni Kurchatov (IAE). The Soviet press reported in early 1983 that 106 "lead" organizations were participating in this program(8). The major goals of the program include the development of a 500-MW heat-generation reactor for nuclear heat supply stations, an 800-MW breeder reactor, a 1,000-MW

Table 2 Estimated Total Available Electric Generating Capacity of Soviet NPS's as of June 1, 1985

Station	Available capacity, MW(e)
Beloyarskiy	900
Novovoronezhskiy	2,409
Shevchenko	150
Kola	1,760
Bilibino	48
Leningrad	4,000
Kursk	3,000
Armenian	815
Chernobyl	4,000
Rovno	808
Smolensk	2,000
South Ukraine	2,000
Ignalina	1,500
Zaporozhye	1,000
Kalinin	1,000
Balakovo(a)	—
Total	25,390

Sources: references (4), (6), (7), (11), (12), and (13).

(a) Planned addition of 1,000 MW of new capacity during 1985.

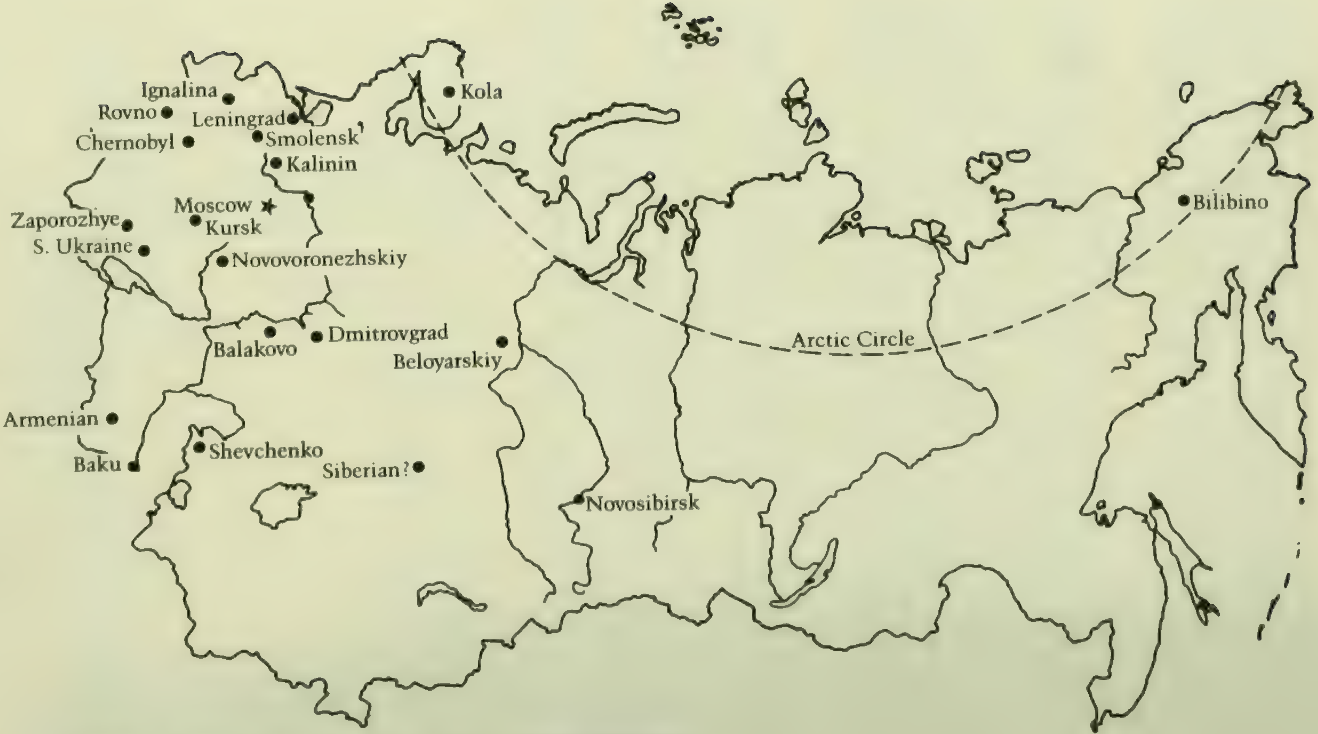

Figure 2 Map of Operating Soviet Nuclear Power Stations, June 1, 1985

turbine to operate with the 1,000-MW reactor at the Rovno NPS, heat-storage nuclear reactors, and NPS's with heightened seismic resistance(9).

Additional objectives of the Soviet nuclear energy program were revealed in March 1984(10). A two-stage development program is foreseen. In the first stage, the expansion of conventional nuclear capacity is to continue, while in the second stage the development of nuclear power for technological processes is to come to fruition along with controlled fusion power engineering. First-stage R&D objectives include work on: recycling uranium and plutonium fuel rods; reducing the consumption of natural uranium by increasing the rate of fuel breeding and by use of more fuel in dense instead of oxide form; expansion of fast breeder capacity; and development of methods for retirement of depreciated nuclear power stations and storage of nuclear waste(10).

Development History

The Soviets continue to pursue the development of both boiling water reactors (BWRS) and pressurized-water reactors (PWRS). The decision to begin reactor development with the BWRS appears to be connected with deficiencies in Soviet manufacturing technology that placed fabrication of heavy steel pressure vessels beyond Soviet capabilities. The first PWR reactor appeared in 1964; since then the PWR has been growing in favor and probably will become the dominant reactor type by the end of the century. The major fission reactor developments are shown in table 3.

*Boiling-Water Reactors.** Following an intensive R&D program, the Soviets began operation of a 5-MW BWR at the Physical-Energetics Institute in Obninsk on June 27, 1954. The Soviets claim that this station is the world's first commercial nuclear power station, but there are those in the West who dispute this claim.**

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*Soviet writings on the history of their nuclear power industry provide virtually the same data. This section draws heavily on pp. 101–13 of reference 14 by A. M. Petrosyants, chairman of the State Committee for Utilization of Atomic Energy (GKAE).

**The dispute centers on the validity of the term "commercial" as well as the term "first." Some Western sources claim the United States first used a nuclear reactor to generate electricity. The Obninsk NPS has or had a significant role besides power generation, namely, research. The Beloyarsk NPS (1964) might be considered the first full-scale commercial NPS in the USSR.

Table 3 Principal Types of Fission Reactors Employed in the Soviet Union

Reactor designation	Reactor capacity, MW (e)	Reactor type (a)	First installation		Current status
			Site-number	Year	
AM(b)	5	BWR	Obninsk-1	1954	Probably retired
Unknown(c)	100	BWR	Siberian	1958	Operating
AMB-100	100	BWR	Beloyarskiy-1	1964	Operating
VVER-210	240(d)	PWR	Novovoronezhskiy-1	1964	Operating
VK-50	62(4)	BWR (vessel)	Ulyanovsk-1	1965	Operating
AMB-200	200	BWR	Beloyarskiy-2	1967	Operating
BOR-60	12	Fast	Ulyanovsk-2	1969	Operating
VVER-365	365	PWR	Novovoronezhskiy-2	1969	Operating
VVER-440	440	PWR	Novovoronezhskiy-3	1971	Operating
RBMK-1000	1,000	BWR	Leningrad-1	1973	Operating
BN-350	350(e)	Fast	Shevchenko-1	1973	Operating
EGP-6	12(f)	BWR	Bilibino-1	1974	Operating
VVER-1000	1,000	PWR	Novovoronezhskiy-5	1980	Operating
BN-600	600	Fast	Beloyarskiy-3	1980	Operating
RBMK-1500	1,500	BWR	Ignalina-1	1984	Operating
BN-800	800	Fast	Beloyarskiy-4	By 1990	Planned(17)

Primary Source: reference(6).

Notes: (*a*) PWR = pressurized water reactor (vessel type), designated VVER in Russian. BWR = boiling water reactor, one series of which is designated RBMK in Russian.

(*b*) AM stands for *atom mirnyy* (peaceful atom)(16).

(*c*) The Siberian NPS reportedly had a total capacity of 100 MW in 1958. In 1976 it was stated that its capacity "significantly exceeds 600 MW"(14). It is not clear how many reactors the station has, what the designations of these are, nor where the station is located. The station nowadays is often omitted from figures on total capacity in the USSR.

(*d*) This capacity reportedly was raised from 210 MW to 240MW in February 1965 and, briefly, to 280 MW in January 1969.

(*e*) If the Shevchenko reactor were used exclusively to generate electricity, its capacity would be 350 MW. In fact, only 150 MW of capacity are devoted to production of electricity, while the balance is used to produce 50,000 metric tons of desalinated seawater per day.

(*f*) This reactor generates commercial heat as well as electricity.

The Obninsk reactor was fueled with 550 kg of uranium fuel enriched (5 percent) with U-235. The design employed a graphite moderator and ordinary (light) water cooling. The fuel elements consisted of a tube-within-a-tube configuration; the coolant was circulated between the tubes and then through a steam generator loop. The superheated steam generated there was then circulated through a secondary loop to the turbine.* In this manner, radioactive water was kept out of the turbine(15).

Construction of the Obninsk NPS permitted experimental verification of the reliability and safety of nuclear power and was followed by additional research on reactor physics and materials. The knowledge thus gained provided a basis for designing larger reactors, namely, the reactors installed at the Siberian and Beloyarskiy NPS's.

Unit I of the Siberian NPS, a BWR of unknown designation, was put on line in 1958. The reactor had an initial output of 100 MW (e). The circulation system uses a double loop circuit with superheated steam in the second loop to drive the turbines. The station generates plutonium, which is used to cover the principal costs of operating the station(14).

Unit I at Beloyarskiy (100 MW [e]) was built between 1958 and April 1964 and is a direct descendant of the Obninsk reactor. This reactor incorporates steam superheating in the reactor core. The reactor fuel is enriched with 1.5-6.5 percent U-235. The large number of fuel rods, evaporative and steam superheating channels, and control rods posed a tough control problem for the designers. Unit II (200 MW) was commissioned in 1967. This unit incorporated reactor steam superheating but eliminated the steam generator and the secondary loop. The single circulation loop has been a feature of large Soviet BWRS ever since.

The next BWR development—the RBMK type reactor—was derived from Unit II at Beloyarskiy, which offered the advantages of producibility (given then-current industrial capabilities), on-line refueling, simple circulation circuit design, and compatibility with Soviet series-produced turbogenerators. The RBMK reactors, however, use saturated instead of superheated steam to drive the turbines.

The RBMK reactors are built on site with standardized components.

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*The second loop appears to have been added at some date after start-up and is connected with tests during design of one of the Beloyarskiy reactors.

Although construction and operating costs are higher than for the VVER series (see below), the RBMK is attractive because of its higher rate of production of plutonium, which will fuel future breeder reactors, and its higher load factor, due to on-line fuel reloading.* The RBMK-1500 appears to be the most sophisticated reactor of this type in the world. Key operating parameters of the RBMK-series reactors are given below(18):

	RBMK-1000	RBMK-1500
Electrical Output, MW	1,000	1,500
Thermal Output, MW	3,200	4,800
Water Consumption in the Active Zone, m.t./hr.	37,500	32,000
Initial Uranium Load, m.t.	192	189
Dimensions of Fuel Rods, mm		
Diameter	13.6	same
Thickness	0.9	same
Steam Parameters Before the Turbine:		
Pressure, MPa	6.5	same
Temperature, °C	280	same
Efficiency, %	31.3	same

The first RBMK-1000 was put into operation at the Leningrad NPS in 1973, and the second (at the same site) in 1975. The Leningrad and Chernobyl NPS's currently are the largest NPS's in the Soviet Union, with 4,000 MW of operational capacity each. These NPS's are to serve as models for other large stations incorporating the RBMK-1000, such as the 4,000-MW station being built at Kursk, and the 7,000-MW (planned) station under construction near Smolensk.**

*Higher operating cost for the RBMKs is reported by Soviet sources, but they may refer to variable cost without taking account of capital costs. It is possible when all factors are considered that the RBMK is cheaper to operate. In any event, the new RBMK-1500 may be cheaper than either the VVER-1000 or the RBMK-1000 on any basis.

**The Smolensk NPS has the largest total planned capacity announced to date. Although the exact composition of the station's reactors is unknown, one possibility is four units of the RBMK-1000 plus two RBMK-1500 reactors.

One 1,500-MW RBMK reactor (with two 750-MW turbine-generator units) went on load near Ignalina in December 1983, and a second is under construction and is slated to go into operation by 1985. Designs of 2,000-MW and 2,400-MW RBMKP reactors (the "P" stands for superheated steam) have been developed, but no dates and sites for the construction of such reactors exist as far as we know. An RBMKP-1200 also has been cited as a possible development(19).

At the other end of the size spectrum, four 12-MW channel BWRS (the EGP-6) are being used at the Bilibino NPS in extreme northeast Siberia for the cogeneration of electricity and heat. The power and heat are being used for the needs of local industries, businesses, hothouses, and households.

To our knowledge, the Soviets have never exported or publicly suggested that they might export boiling-water reactors such as the RBMK-1000 to Eastern Europe or other parts of the world. Perhaps this is because of the plutonium-production capabilities of this type of reactor or their high investment cost relative to the VVER-series reactors.

*Pressurized-Water Reactors.** The USSR has developed a series of PWRS that are light-water cooled and moderated. The Soviet PWRS closely resemble PWRS designed in the West. In contrast to the RBMKS, the PWRS incorporate a double-loop circulation system. The PWR is believed to be quite reliable, although perhaps more dangerous than the BWR due to the higher pressures. The PWRS have the benefit of factory-grade construction quality and can be transported by rail. A major disadvantage, compared to the RBMK, is the need for complete shutdown prior to refueling.

Three generations of VVER-series PWRS may be noted(14). Initial installation of all VVER reactor types was at the Novovoronezhskiy NPS. The first generation reactors (the VVER-210 and VVER-365) are still operating. The Soviets have experienced problems with the VVER-210. Sometime after installation of the VVER-210 (September 1964) radioactive cobalt from the main circulation pump bushings was found in the primary circulation loop. Bushings using a noncobalt alloy were developed to replace the troublesome bushings(14). In 1969 it was discovered that the thermal shield within the reactor vessel had broken away from its supports and was resting on the bottom of the reactor vessel. It was determined that the shield was not needed and a redesigned reactor core was substituted for the original(14).

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*This section draws heavily on pp. 126–32 and 135 of reference (14) by A. M. Petrosyants.

The second generation reactor, the 440-MW VVER-440, became the standard Soviet PWR until the early 1980s. At present, nine such reactors are in operation in the USSR, and a tenth is under construction at the Kola NPS. In addition, as of late 1983 two VVER-440s had been installed in Finland and eleven had been installed in Eastern Europe. Another four to five VVER-440s are now under construction in East Europe, but some of these are Czech-made reactors.

A third generation PWR—the 1,000-MW VVER-1000—was put into operation in 1980 at Novovoronezhskiy; a second was commissioned at the South Ukraine NPS in late 1982. The VVER-1000 is to become the standard domestic PWR, replacing the VVER-440 in this role. Key operating parameters of the VVER-440 and the VVER-1000 are given below(18):

	VVER-440	VVER-1000
Output, MW		
Electrical	440	1,000
Thermal	1,375	3,000
Flow of Water Through the Reactor, m^3/hr	42,600	80,000
Average Enrichment of Initial Loading, %	3.6	4.4
Water Temperature, °C		
Reactor Inlet	270	290
Reactor Outlet	298	322
Reactor Hull Dimension, m		
Diameter	3.84	4.5
Height	11.8	10.88
Fuel Rod Dimensions, mm		
Diameter	9.1	same
Thickness	0.65	same
Number of Fuel Rods	126	317
Efficiency, %	32.0	33.0

The BWR currently is the most widely used commercial power reactor in the USSR, accounting for nearly two-thirds of the installed capacity. However, new industrial capacity now is being assimilated to produce large PWRS on a series basis in the USSR and Czechoslovakia, which will permit a reorientation toward the PWR in future NPS's. Over the next decade new nuclear capacity is expected to be divided roughly evenly between the BWR and the PWR, but beyond that the situation is uncertain.

The BWR design organizations appear to be feeling the bite of competition from the PWRS and frequently publish reminders of the BWR's advantages (and also of the disadvantages of the PWRS). The size limitations of the PWRS and their requirements for more highly enriched uranium are commonly found criticisms(20). Larger BWRS are now on the drawing boards, but the prospects for their ultimate manufacture and use may well depend on the ability of the BWR designers to sell the government on continuing to support the installation of two basic types of reactors. (The initial emphasis on the BWR reactor, however, may have been dictated largely by Soviet technical and manufacturing constraints that delayed commercialization of the PWR reactors. As these deficiencies were removed, the rationale for pursuing the RBMK line of development may have lost its appeal.)

Reactor Manufacture

Industrial capability to produce reactors in the USSR and Eastern Europe is concentrated in three organizations: the "Atommash" and "Izhora" production associations in the USSR and the Škoda-Plzen concern in Czechoslovakia. Since the Soviet monopoly in this area is giving way to a CMEA cooperative effort and division of labor, a few words on the East European efforts also are included below.

The "Atommash" Plant. The USSR now is on the verge of an era of mass production of standardized commercial reactors that soon are to begin to flow from the "Atommash" Production Association (PO) imeni L. I. Brezhnev(21).

The association's principal plant—the Volgodonsk Heavy Machine Building Plant, better known as the "Atommash" Plant—still is under construction. As the plant is gradually brought to capacity over a period of years, it is expected to initiate an era of mass production of commercial nuclear power facilities. The plant will produce major components for nuclear reactors, such that minimum assembly will be required at the installation site. The large main building at Volgodonsk will house 15,000-ton presses, manipulators capable of handling parts and assemblies weighing up to 1,000 tons, and rolling mills for forming heavy plate. According to sources from the mid-1970s, the entire complex, comprising three production plants and a high-rise engineering building, will occupy an area in excess of 650 hectares (1,610 acres)(22, 23).

During the Eleventh Five-Year Plan, "Atommash" is to supply a total of seven VVER-1000 reactors (for installation at the South Ukraine, Kalinin, and Rostov NPS's)(21, 24). During the Twelfth FYP (1986–90), the production rate is to reach six to seven units per year, and—by 1990—eight units per year(21).

The general contractor for the project—Volgodonskenergostroy*—has encountered numerous problems, including acute shortages of workers, shortages of motor transport, and insufficient supplies of building materials. As a result, construction schedules have been slipped badly(21).

The Soviet effort is dependent on adding production capacity at a number of other plants as well. In 1980 plants were being built at Kursk and Zaporozhye for the supply of auxiliary equipment for nuclear power stations under construction. The capacity of the Zaporozhye industrial facility will be 40,000 tons of products a year(25). Early in 1981 the "Energomashspetsstal" Plant in Kramatorsk became a major supplier of power machinery for nuclear power stations(26).

The Soviets claim that nuclear reactor parts produced at Atommash are subjected to rigorous examinations to guarantee reactors a thirty-year period of trouble-free operation(24,27).

The Production Association "Izhorskiy zavod" imeni Zhdanov. Production equipment for the RBMK series reactors is focused within the "Izhora" Association in Leningrad. Until the "Atommash" plant comes fully on line, Izhora will remain the Soviet Bloc's main reactor manufacturing center.

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*The Volgodonsk Power Construction Trust of the USSR Ministry of Power and Electrification(21).

Izhora produces VVER-440 reactors and the main systems for the RBMK-1000 and RBMK-1500 reactors(28). Eventually, responsibility for VVER-440 reactor production is to be transferred entirely to Škoda-Plzen in Czechoslovakia (see below)(29). Izhora was reconstructed in the Tenth FYP at a cost of R300 million. The reconstruction affected nearly every shop and increased production floor space to over 100,000 m^2(30). Izhora's output is said to have doubled over the period(31).

CMEA Cooperation. Cooperation in the area of nuclear power equipment was formalized in a 1978 CMEA agreement on long-term technical interaction and mutual supply of key equipment for NPS's. The current agreement runs from 1981 to 1990(32). Around fifty plants in CMEA, including Yugoslavia (an associate member of CMEA), will participate; about one-half of the required volume of equipment for the CMEA program will come from the USSR(32).

The Soviet Union's major East European partner is Czechoslovakia, although Poland, Hungary, and Bulgaria contribute in a material way. Codevelopment of the major types of equipment (such as reactors, turbines, electric generators, pumps, and tubing) is concentrated in the USSR and Czechoslovakia, while auxiliary equipment (such as water treatment equipment, cooling systems, electrical equipment, and shielding) are being developed and produced in the other countries mentioned above(33).

The major Czech firms are the Škoda-Plzen Group; the Vitkovice Group (the Klement Gottwald Metallurgical and Engineering Combine); the Sigma Pump Concern; the Chomoutov Tube Rolling Plant; the Poldi-SONP Steel Plant in Kladno; the Modrana Machine Plant near Prague; the First Brno Engineering Plant; and the Tlamace Group Enterprise. Škoda-Plzen is the plant of greatest interest. Plans for this plant call for the production of fourteen VVER-440 reactors between 1981 and 1985, and nineteen by 1990(34, 35). Škoda-Plzen also plans to produce the VVER-1000 sometime in the future(35). The Vitkovice Group has been supplying heavy castings for the VVER reactors for several years(36).

Several instances of Soviet-Czech R&D cooperation have been identified in the Czech press. The Sigma plant, for example, has worked with the Soviet Union's VNIIGidromash on the development of a 7.7 m^3/sec pump for cooling steam turbine condensers(37). The First Brno plant worked with the Soviet Union's All-Union Project

Design Institute of Power Engineering on heat and pressure treatment of turbine blades(38).

Poland, the apparent number two partner of the USSR, is specializing in the production of auxiliary generators and safety systems(39). The primary Polish plants are the Zgoda plant in Swietochlowice (standby diesel generators for cooling systems); the Zamech enterprise in Elbag (500-MW turbines); and the Polon enterprise in Zielona Gora (measuring systems).

Thermal Fission Reactor Problems

Introduction

The Soviet nuclear electrification program is well into the commercial phase, in that the production of standard reactors has begun and emphasis is shifting to the routine production of power. Nevertheless, R&D efforts continue as the Soviets seek to improve equipment designs, to increase the efficiency of the nuclear sector, and to meet operating problems that they have encountered or expect to encounter in the future. This section discusses Soviet R&D efforts directed at problems with steam generators, turbines, and electric generators, as well as efforts to develop load-following NPS's.

Steam Generation

The mode of steam generation adopted at the Beloyarskiy NPS and all RBMK reactor stations incorporates a single-loop cooling system that supplies weakly radioactive steam to the turbines directly from the reactor. The turbines are housed in conventional industrial-type buildings, but the steam pipes are said to be encased in concrete. The problem at Beloyarskiy is heightened by the use of reactor superheating in which the steam is recycled through the reactor before entering the turbine. To counteract the radiation effect, the heat-emitting elements and reactor channels are protected with thick, neutron-absorbing shells of an expensive stainless steel, making the Beloyarskiy NPS less economical than stations with dual-loop cooling systems. For this reason, development of NPS's like the one at Beloyarskiy was not pursued. However, the experience gained there is being utilized to develop a channel-type, graphite-moderated reactor with a rated capacity of 2,000 MW. While this reactor also is designed to superheat the steam, the stainless-steel linings of the channels in the core have been replaced with cheaper zirconium-alloy linings(40).

At present most Soviet NPS's run on saturated steam; the only superheating that occurs is accomplished in so-called separator-superheaters, which treat the steam as it passes between the cylinders of the turbine set. There is some evidence of problems with these superheaters. During start-up procedures at the Chernobyl NPS, deficiencies in the design and manufacture of the superheaters reportedly made it necessary to turn them off several times, thus reducing the effective capacity of the turbines(41). Other problems were encountered with the station's conventional drum-separators (which left the steam too moist and thus accelerated erosion of the turbine blades); with the devices that regulate the delivery of steam to the turbines; and with cutoff switches connecting the generators with the station's internal power system(41).

Turbines

In principle, the power generation equipment for thermal power stations (TPS's) and NPS's is essentially the same. This is particularly true with respect to the turbines. Up to 1978, at least, the designs of steam turbines for nuclear stations often duplicated designs or incorporated design features of turbines for thermal stations(42). Therefore, it is likely that problems encountered with turbines in one type of station also are encountered with those in the other type.

One of the most persistent and damaging problems with the Soviet turbines in general is erosion of the blades and also of nonmoving parts. The rapidity and extent of erosion depend on many factors, including turbine speed, the moisture content and pH level of the steam, materials and techniques used to fabricate turbines, and operating conditions of the latter(42). The fact that most Soviet NPS's run on saturated rather than superheated steam may aggravate the erosion problem at these stations.*

Blade erosion is aggravated by the relatively high-speed operation of the large Soviet turbines. The standard 500-MW turbines for the RBMK-1000 reactor and the 750-MW turbines for the RBMK-1500 turn at 3,000 rpm. A 1,000-MW, 1,500-rpm turbine has been installed at the Smolensk NPS, and two 500-MW, 1,500-rpm turbines have been installed at the Novovoronezhskiy NPS. The switch to the lower turbine speed requires the use of a substantially larger rotor and a four-pole generator in place of bipolar generators. The large turbine rotor may have presented manufacturing obstacles in casting and machining that are slowing the diffusion of this technology. In addition, the heavier turbines may prove difficult to transport to those RBMK sites that are remote from rail lines and navigable rivers.

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*This problem arose during the operation of turbines on saturated steam at the Kola NPS. To combat erosion, stainless steel was used to protect or replace certain parts inside the high-pressure cylinders of the turbines(43).

Generators

As with steam turbines, turbogenerators for power plants are essentially the same for both thermal stations and NPS's, with some generators able to operate in either type of station(44).

One feature that distinguishes generators for TPS's from those for NPS's is the generators' rated capacities. This is particularly true of the latest operational and planned generators with capacities greater than 500 MW. A major trend in Soviet power engineering is to build stations with larger and larger unit capacities. To meet the needs of these stations, generators have been designed with rated capacities of 800 MW and even 1,200 MW for TPS's, and 1,000 MW and 2,000 MW for NPS's. It may be noted, however, that a new 1,000-MW unit being developed for NPS's at the "Elektrosila" Electrical Machine Building Production Association in Leningrad—a well-known producer of turbogenerators—is said to be basically analogous to the 800-MW unit that is in operation at several thermal stations(45).

The "Elektrotyazhmash" Plant in Kharkov has been assigned the task of developing turbogenerators with capacities of 500 MW and higher for NPS's with thermal-neutron reactors(44). This work is said to be possible thanks to the plant's extensive experience in designing generators for conventional stations(44). In this regard, the plant reportedly encountered difficulties with its first 500-MW unit for TPS's; the task of developing this type of generator was found to be "much more complicated" than was initially thought. Although the difficulties were not specifically described, numerous measures having to do with the generator's design, testing, and methods of production reportedly were taken to ensure the generator's reliability(44). The plant also manufactured the USSR's first two 500-MW generators for a nuclear station—the Novovoronezhskiy NPS(44).*

Load Following

Because of the dominance of industry in Soviet electricity consumption, overall power demand in the USSR traditionally has been more regular than in the United States. Nevertheless, the Soviet power system has had difficulty coping with variations in demand (or load), particularly peak-load periods. The peaking problem has been growing over the years with the increase in power consumption by nonindustrial sectors, such as agriculture and residential customers, and this problem is expected to intensify in the 1980s as consumption by these sectors increases(46).

Soviet writers have devoted a great deal of attention to the need for load-following nuclear power units because, in the forseeable future, rapid nuclear electrification of the western part of the USSR is expected to bring that region to the point where nuclear capacity will exceed the base demand for electricity. According to Soviet sources, it will become necessary to operate some NPS's with "regulated load conditions" once nuclear plants account for 25 to 30 percent of generating capacity(47).

Several problems are encountered when the load on an NPS is varied. First, because of the high level of fixed costs associated with a nuclear plant, production and revenues decline sharply when the plant is powered down, but most costs continue. As a result, the economic advantage of nuclear power declines sharply. Second, a number of technical problems arise. For one thing, repeated movement of fuel rods into and out of the core associated with variations in power levels results in repeated changes in the temperature of the fuel rods and, thus, thermal stress on the rods. As an example, one Soviet source reports that a 1 percent change in power leads to a 15–20°C change in the temperature gradient in the cross section of common rod-type fuel elements (made of sintered uranium dioxide). Repeated exposure to such changes can cause premature failure of the fuel element. As one solution to this problem, Soviet researchers have been studying the feasibility of using tubular rather than rod-type fuel elements(47).

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* Standard Soviet practice has been to use two 500-MW generators with each 1,000-MW power unit at NPS's. Unit 1 of the South Ukraine NPS, which was commissioned in December 1982, is the first case where a 1,000-MW (pressurized-water) reactor has been combined with a turbogenerator of the same capacity(12).

In addition to this particular research effort on tubular fuel elements, N. A. Dollezhal, a pioneer of Soviet nuclear electrification, has pointed out a number of technical problems that will have to be solved if successful load-following plants are to be developed(48). These include removal of limitations on the number of start-stop cycles for the equipment of NPS's; choice of the best fuel, fuel shells, and designs of heat-emitting elements; and optimization of reactor control and protection systems. Moreover, the operating conditions for all NPS's will have to be improved, given the poor economic indicators of NPS's operating under variable loads. In this regard, Dollezhal discussed the possibility of developing modified thermal-neutron reactors specially suited to semi-peak loads.

Increasing the load-following capability of nuclear power units, which until recently were designed to operate only under base loads, was seen as an urgent need several years ago(49). Some trials subsequently were conducted at Soviet NPS's to determine the feasibility of running these stations under variable loads(50, 51). In addition, an all-union conference was held in 1977 to discuss results of research on this problem(49).

A second approach to the load management problem is to combine nuclear power stations with pumped-storage hydroelectric power plants. Under this option, excess electricity from an NPS is used to pump water to a height. When power demands increase, power from the NPS is sent out to consumers and is supplemented at peak periods with hydroelectric power produced by the water pumped up during the low demand period. (The Soviet pumped-storage program is discussed in more detail in chapter 6.)

Fast Breeder Reactor Programs

Basic Programs

A characteristic feature of the Soviet nuclear program is the heavy emphasis placed on the fast-breeder reactor. A number of Soviet authorities believe that uranium supplies will be exhausted by the year 2000 and that the Soviet Union should make a large-scale conversion from conventional reactors to the breeder before that time comes.

In furtherance of this goal, the Soviet Union has been actively pursuing research on fast reactors for the past three decades. According to O. D. Kazachkovskiy, director of the Physical-Energetics Institute (FEI) in Obninsk, systematic Soviet efforts began in 1950 under the leadership of A. I. Leypunskiy(52). The first significant Soviet fast reactor, the BR-5 (having thermal output of 5 MW), became operational in 1958 at FEI in Obninsk(52). A second fast reactor, the BOR-60 (with a thermal output of 60 MW), was put into service in 1969 at the Scientific Research Institute of Atomic Reactors (NIIAR) at Dimitrovgrad(52). These experimental reactors allowed the Soviets to move from theoretical to engineering efforts at an early date and helped them gain valuable experience with the use of liquid sodium as a heat carrier and to test fuel elements made of plutonium dioxide(52).

These initial efforts were followed in 1973 by the opening of the world's first commercial (demonstration) fast reactor—the BN-350—at Shevchenko on the Caspian Sea coast. This reactor is shown in figure 3. A second commercial fast reactor, the BN-600, was commissioned at the Beloyarskiy NPS in 1980 (seven years after its originally scheduled completion date)(6). Key operating parameters of the BN-series breeder reactors are given below(18):

	BN-350	BN-600
Power Output, MW		
Electrical	350	600
Thermal	1,000	1,470
Maximum Temperature of Coolant, °C		
First Loop	500	550
Intermediate Loop	450	520
Steam Parameters Before the Turbine		
Pressure, MPa	4.9	14.2
Temperature, °C	435	505
Fuel		
Active Zone	UO_2	same
	$UO_2 + PuO_2$	same

Screens	UO_2	same
Mass in the Active Zone, 10^3 kg	7.3	8.5
Breeding Rate	1.0–1.4	0.9–1.3

Experimental data indicate that the BN-350 has a breeding rate of 1.05, plus or minus 0.05. This is similar to the breeding rate of the French Phénix demonstration breeder (1.03 to 1.08), but is quite a bit lower than the rate planned for the U.S. Clinch River breeder (1.33)(53, 54).

For several years the Soviets talked of having their third commercial fast reactor (called the BN-1600) be a 1,600-MW unit and spoke of plans to begin construction in 1983 and bring the unit on line in 1989 (17, 55). More recently they have indicated that the third commercial fast reactor will have only 800 MW of capacity (although future stations might have two units for a total of 1,600 MW)(17). This new fast reactor, called the BN-800, will have a pool design very similar to that of the BN-600 but will use once-through steam generators that produce saturated steam; this is in contrast to the BN-600 that has multiple straight-tube units for evaporation, superheating, and reheating of the sodium(17). Detailed design work on the BN-800 reportedly began before the end of 1981, and construction (at the Beloyarskiy NPS) is to be completed by about 1990(17).

Fast reactors, excluding the research breeder reactor at Dimitrovgrad, accounted for less than 4 percent of Soviet-installed nuclear capacity as of January 1, 1984. In 1980, when the BN-600 was commissioned, Aleksandrov indicated that fast reactors would account for 30 percent of the electric power generated by Soviet NPS's by 1995(56). Such a share is clearly unattainable. If only the 80,000 MW now under construction are added to the nuclear power capacity, well over 40,000 MW of breeder capacity would have to be added to achieve this goal.

A major concern of past and present Soviet research on fast reactors has been with heat carriers. Early studies investigated a number of candidate substances, including sodium, alloys of sodium and potassium, alloys of lead and bismuth, and helium. Water was ruled out because of its neutron-deceleration properties.

The Soviets have devoted most of their attention to liquid sodium as a heat carrier because it allows for efficient removal of heat and does not require high pressures. However, there has been great concern about the safety of employing a material that is so highly reactive with oxygen and water—particularly when reactor outlet temperatures are to be over 500°C—and large quantities of sodium (about 900 m.t.) are to be in use. Such concerns were not ill-founded, and it is evident from Kazachkovskiy's remarks that accidents occurred with the BN-350 during the early stages of its operation(52).* Safety of fast reactor operation has received emphasis in Soviet research during the 1970s, as indicated by several articles in the Soviet journal *Atomnaya energiya.*

Heat-carrier R&D continues to focus on liquid sodium, but attention also is being given to the possible use of gaseous heat carriers, such as helium and dissociating gases (e.g., nitrogen tetroxide, N_2O_4)(52). As of February 1981, design organizations of the GKAE, working under the guidance of, and in collaboration with, the Institute of Nuclear Energy of the Belorussian Academy of Sciences in Minsk, had drawn up the blueprints of a pilot industrial NPS with a 300-MW gas-cooled fast reactor. According to N. M. Sinev, a deputy chairman of the GKAE, dissociating coolants can serve as the working medium in such reactors. Work on this technology by scientists of this institute was said to have helped accelerate construction of the USSR's first pilot industrial NPS with a fast reactor using dissociating gas (presumably the same plant mentioned above)(60). Apparently the Institute of Problems of Strength, under the Ukrainian Academy of Sciences in Kiev, has assisted the institute in Minsk in designing an experimental unit for studying the creep and long-term strength of reactor structural materials under fast-neutron irradiation, high temperatures, and a circulating, dissociating N_2O_4 coolant(61). Sev-

*Kazachkovskiy indicated that there were leaks in the pipes of the BN-350's steam generator through which hundreds of liters of water entered the sodium. Evidently no one died as a result of this accident, which Kazachkovskiy termed "fairly unpleasant," but repairs were very labor-intensive and forced a curtailment of operations at the Shevchenko facility(52). Another source reports that a cooling pipe ruptured, causing a large sodium explosion(57). One of the six original cooling pipes remained irreparable for years, and, as of mid-1980, the plant was reported to be operating at only 65 percent of capacity(57). Perhaps this is why one Soviet source(58) reported in May 1980 that the plant was desalinating 50,000 m.t. of water per day, while an earlier source reported that it was processing 120,000 m.t. per day(59).

eral Soviet technical articles on the chemical and thermodynamic properties of N_2O_4 were published in 1981 and 1982.

These various fast reactors have provided the Soviets with a strong experimental base for the design and eventual construction of one or more standard lines of fast breeder reactors. In fact, A. N. Grigoryants, head of the Main Administration for the Use of Atomic Energy (Glavatomenergo) of the USSR Ministry of Power and Electrification, stated in 1973 that construction of fast reactors will constitute the general line of future development of nuclear power in the USSR(59). However, according to a 1984 article by G. Shasharin, a USSR deputy minister of power and electrification, the existing Soviet breeders were not yet breeding at a rate high enough (see above) to produce enough new fuel to supply a new reactor with fuel or even to satisfy their own fuel needs(62). The fuel-cycle aspect of fast-reactor operation has received considerable attention in the Soviet technical literature during the past twenty years. Recovery of useful fission products is planned, in addition to the bred fuels.

The Soviets reportedly are promoting a hybrid system of breeder technology that combines a tokamak* fusion reactor system (see below) with a conventional reactor to produce an especially intense neutron flux. Yuriy Kartinsen of IAE says that the hybrid system would decrease the doubling time by a factor of ten(55).

Supporting Technologies

Development of the following support technologies has been pursued aggressively since the 1970s:

Corrosion-resistant construction materials for use at high temperatures in a radiation environment.
Fuel materials with improved stability and compatibility.
Thermodynamics and chemistry of liquid-metal and gaseous reactor coolants and working media.
Complex water chemistry in high-temperature components.
Technologies for recycling fissionable material in spent fuel rods.
Effective disposal of nuclear wastes.

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*Tokamak is a Russian language acronym meaning "toroidal chamber with magnetic coils" (*toroidalnaya kamera s magnitnimi katushami*).

Fatigue and fracture mechanics of highly stressed construction materials.

Judging from the available Soviet literature, the Soviets have made significant progress during the past decade. For example, they have been developing and testing nuclear fuels based on the carbides and nitrides of uranium. These compounds and their plutonium counterparts can be used to advantage in place of oxide fuels in fast reactors.

Evaluation of the Fission Programs

Likely Fields of Application of Results

The most common use of nuclear energy is in the generation of electrical power. Nuclear reactors of suitable design can be coupled to steam power plants to produce electric power at high output, presently up to 1,500 MW.

There is, however, a great amount of waste heat from a nuclear-steam power cycle, and the Soviets have made use of this heat in some locations for "district heating" (or cogeneration). By going to higher temperature, higher pressure steam conditions, they have demonstrated that they can triple the specific power output in the district heating mode of operation. New turbomachinery generating units with 250- to 350-MW capacities have been developed for district heating to operate under supercritical steam conditions. The Soviets claim that they lead the world in unit capacity of district heating turbines and heat-and-power stations. Between 1974 and 1976 the Soviets commissioned units of the world's first district heating nuclear power station—the Bilibino NPS—which has four district heating turbines of 12-MW capacity each(6).

In the process of developing a new complex of power stations across their country, the Soviets are in an excellent position to consider the applicability of district heating at appropriate sites and to justify the additional capital cost. Such development may be particularly appropriate in the northern half of the European part of the USSR, where fossil fuel is costly, manufacturing is intensive, and average temperatures are low. In 1978 the efficiency of district heating power plants was claimed to be 25 to 30 percent higher than that of conventional power plants(6).

The Soviets have adopted a basic construction-planning rule that nuclear electric plants must be distributed in succession from west to east, in opposite direction to the expected flows of fossil fuels from Siberia(64). The rationality of this rule of thumb has been supported by the results of mathematical modeling of various aspects of the proliferation of nuclear power plants in the Soviet Union. One model employed in this activity was developed in 1969–70 at the Siberian Power Engineering Institute(64). (See chapter 8.)

The Soviets have been developing highly efficient new types of nuclear reactors for production processes requiring high temperatures. A reactor with a thermal capacity of 1,000 MW, for example, is capable of providing the necessary heat for two chemical combines with an annual output of 1 million m.t. of ammonia each, or for two metallurgical plants with an annual output of more than 2 million m.t. of steel(65). The gas employed in this high-temperature, gas-cooled reactor (VTGR) is heated to a temperature of almost 1,000°C at the outflow.

In the mid-1960s, the Soviets foresaw the possibility of employing such reactors in improved production processes—for producing iron by direct reduction, for example (thereby making blast furnaces unnecessary)(66, 67, 68). Furthermore, coal can be gasified or liquefied directly in mines with the aid of a VTGR. An experimental industrial atomic power-and-technological plant using a reactor with a thermal capacity of 1,000 MW was reported to be under development in the USSR in 1980(65). Such plants could be used for the production of both electricity and hydrogen, by using helium coolant operating at temperatures of 800° to 900°C(68).

During the 1970s well-placed Soviet sources indicated their anticipation of the eventual use of nuclear energy for refrigeration, production of hydrogen, and desalination of water(66, 69). In 1976 A. P. Aleksandrov predicted that by the mid-1990s hydrogen would be needed in large quantities as a low-pollution fuel for internal combustion engines, gas turbines, and rocket engines and commented that the use of nuclear energy is a promising method of hydrogen production (from water)(66, 67). (For more on nuclear-based production of hydrogen, see chapter 7.)

Significance of the Effort

The Soviet nuclear electrification program is funded at a very high level. The Office of Technology Assessment has estimated that proposed additions to nuclear capacity during the Eleventh FYP will cost 9.1 billion to 9.5 billion rubles and could absorb 80 percent of all funds available for the electric power industry during 1981–85(70). Research costs in 1975 were estimated at 90 to 97 million rubles and probably are substantially higher now(71). The large funding results partially from the Soviet government's ambitions for nuclear electrification and partially from the high capital cost of research installations and prototype nuclear power plants.

Technical Feasibility

At least sixteen Soviet nuclear power plants have been placed in operation since 1954, and the Soviets claim they have encountered no insurmountable problems with these plants. The United States has had similar experience regarding technical feasibility and operational reliability of nuclear power plants. Problems encountered have been essentially of an engineering nature and, except perhaps for the long-term storage of nuclear wastes, solutions have been achieved.

The Soviets profess not to be concerned about the nuclear accident at Three Mile Island and argue that this accident is attributable to the shortsightedness of capitalist owners. However, repeated references to the accident in the Soviet press suggest that the Soviets are concerned with nuclear safety. In the summer of 1983 a State Committee for Supervision of Work Safety in Nuclear Power Engineering (Gosatomnadzor) was formed by the USSR Supreme Soviet(72). The new state committee is headed by Ye. Kulov, a former deputy minister of the Ministry of Medium Machine Building, which appears to be responsible for nuclear weaponry(73, 74). The committee is responsible for ensuring compliance with rules and standards of nuclear safety in the design, construction, and operation of nuclear power stations(75).

Economic Considerations

While the overall plant efficiency of a nuclear power plant is not quite as high as for conventional fossil-fuel-fired power plants (about 33 percent versus a maximum of 40 percent), the operating cost of a nuclear plant compared to a fossil-fuel plant of the same power output can be somewhat less, depending on the location and the relative fuel costs at that location. V. A. Kirillin, then chairman of the USSR State Committee for Science and Technology (GKNT), indicated in 1975 that in areas remote from fossil fuel resources, the cost per kwh is less for nuclear plants than for fossil-fuel-fired power plants. Thus, despite higher capital costs of nuclear plants, their general economic characteristics under these conditions are better than those of the fossil-fuel plants(76). In 1977 a Soviet official indicated that the cost of power generation at the Novovoronezhskiy NPS was 30 percent lower than that of coal-fired power generation(77).

In pursuit of this regional theme, Gosplan USSR in 1979 published a study of the cost of providing electricity to three broad regions of the Soviet Union (the Center,* the Urals, and Siberia) using various generating sources (hydroelectric power, atomic energy, natural gas, and various types of Siberian coal)(78). Several conclusions emerge from cost figures developed by that study. First, because of transmission expenses, the delivered cost of a kilowatt hour of electricity produced in Siberia rises as it is carried farther and farther west. Second, and perhaps less obvious, the cost of a kilowatt hour of electricity from an atomic power plant increases (by up to 10 percent) as the site of the atomic power plant is moved farther east(78). (This is probably because of higher labor and other construction costs and higher costs of shipping components from manufacturers as the plant site is moved farther east.)

In the central economic region, centered on Moscow, electricity generated by local atomic power plants is cheaper than electricity from any other source except local plants fired by natural gas. Power shipped from Siberia is estimated to be more expensive in the Center than nuclear power irrespective of the fuel used in Siberia(78).

However, electricity from nuclear power is not competitive in the Urals or in Siberia with coal-generated power transmitted from Siberia. Power from Siberian hydroelectric power plants is more expensive than atomic power in the Urals but less expensive than atomic power in Siberia(78).

If these projected costs are indicative, it would be economically rational for the Soviets to supply most, if not all, of the additional electricity needed in the Center with nuclear power. (Troitskiy indicates that any available natural gas should be substituted for fuel oil in existing oil-fired plants.) However, it does not appear to be economically rational at the present time to build atomic power plants in the Urals area or in Siberia.

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*The "Center" is an economic region that includes the city of Moscow and areas surrounding it.

Finally, Soviet planners have studied the backward linkages generated by nuclear power as opposed to other forms of power generation. As a result of these studies, it has been concluded that developing nuclear power generation will result in reduced consumption of ferrous metals, cement, and timber but increased consumption of high-quality steel, nonferrous metals, and scarce metals. In addition, the productivity of labor is expected to be enhanced(64).

It is more difficult to judge the economics of fast reactors. In his 1980 analysis Kazachkovskiy seems to indicate that the capital cost per kw of capacity now is higher for fast reactors than for traditional ones because of the greater technical complexity of the former. However, he points to the lack of a vessel operating at high pressures and the great compactness of fast reactors as advantages that eventually will swing the economic pendulum in favor of the fast reactor, especially as fast reactors of greater unit output are created(52).

Thermonuclear Fusion Programs

Introduction

In contrast with nuclear fission, where energy is released by splitting atoms, thermonuclear fusion involves the uniting of hydrogen isotopes in a high-temperature plasma to form helium atoms and a flux of energetic neutrons. Because the world has an almost inexhaustible supply of suitable hydrogen isotopes, a technology for applying thermonuclear fusion in a controlled manner might provide a major contribution to solution of mankind's energy difficulties.

The principal technical problem in the development of a controlled nuclear fusion reactor is to achieve sustained net energy output in a controlled environment—a difficult task, given the very high temperature and pressure conditions required.

Two basic approaches have been taken to obtain the required combination of pressure (particle density), temperature, and confinement time: (1) magnetic confinement, and (2) inertial confinement. In the first approach the reacting particles are trapped and pressed together by a strong magnetic field. In the second a microsphere of the hydrogen isotope is greatly compressed by a number of high-energy beams, such as laser or electron (particle) beams.

Magnetic Confinement

Introduction. The Soviets have made a major contribution to magnetic confinement R&D by developing what has become the most widely used technique: the tokamak reactor. The tokamak concept was first proposed by A. D. Sakharov and I. Ye. Tamm in 1950, probably as a spin-off from work on the first Soviet hydrogen bomb, which Sakharov is credited with developing. Experimental research on the tokamak concept began in 1956 at IAE under the direction of L. A. Artsimovich(79). In this type of reactor, plasma is created and held in a toroidal chamber such that it can be compressed in a closed loop by a very strong magnetic field generated by heavy electrical windings surrounding the torus. The present-generation Soviet tokamak (e.g., the T-10) has come within an order of magnitude of the criteria for net output (plasma density times confinement time must be greater than 10^{14})(80). Magnetic confinement reactors, if they are operated in the steady state, can make use of direct energy conversion, either electrostatic decelerator concepts or MHD, to generate electric power from the fusion energy.

The T-10 tokamak was designed for heating plasma primarily by means of the current flowing in the confined plasma. As a result, its peak temperature is 15 million degrees centigrade. The T-10 is the world's first 180-MW pulse installation to draw its power directly from the commercial electric network. Although its energy consumption per pulse amounts to 150 MJ, its design avoids the need for energy storage by being connected to the net through controlled thyristor rectifiers. This feature results in simplification of the power supply and greater reliability(81).

The IAE has played an important role in the development of successive versions of the tokamak reactor such as the T-7, as can be seen from table 4. The capabilities of the T-7 reactor have been increased over those earlier reactors by the use of superconducting windings. The confinement chamber of the T-7 reactor is shown in figure 4. The most significant fusion effort at present is the development of the T-15 tokamak, which is expected to be operational at IAE in

Table 4 Soviet Experimental Controlled Fusion Installations

Designation	Date operational	Type
IAE imeni Kurchatov (GKAE)		
T-10	1977	MC* (tokamak)
T-7	1979	MC (tokamak)
T-10M	1983	MC (tokamak)
T-15	1986	MC (tokamak)
Ogra-4	1979	MC (open type)
Angara-1	1978	IC** (electron beam)
Angara-5	1979 (first module)	IC (electron beam)
Physics Institute imeni Lebedev (AN SSSR)		
Kalmar	1970	IC (laser beam)
Delfin	1979	IC (laser beam)
Delfin-1	1981	IC (laser beam)
Institute of Nuclear Physics (SO AN SSSR)		
PSP-2	1982	MC (centrifugal)
Ambal	1983	MC (ambipolar)
Gol-3	1981	IC (laser beam)
Physical-Technical Institute imeni Ioffe (AN SSSR)		
Tuman	ca. 1980	MC (tokamak)

*Magnetic confinement

**Inertial confinement.

1986.* The T-15 belongs to the same generation of fusion experiments as the U.S. Tokamak Fusion Test Reactor (TFTR), the Japanese JT-60 tokamak, and the Joint European Torus (JET) of the European Economic Community, but it may be the smallest in the group.

The T-15 Tokamak. Equipment for a new, large tokamak, known as the T-15, now is being built at the "Atommash" plant(82). The T-15 was designed by the Scientific Research and Design Institute of Electrophysical Apparatus imeni Yefremov of GKAE in Leningrad with the intention that the equipment be produced at the "Elektrosila" association, also in Leningrad, but the task turned out to be beyond the competence of Elektrosila, and the job was assigned to Atommash where design modifications were required to fit the new production conditions(82). Atommash will produce the vacuum chamber, the toroidal-field magnets, and the vacuum shielding, while a number of other Soviet plants will produce other equipment. The T-15 will be installed at IAE where it will be used to study the feasibility of commercial fusion power stations(83). The T-15 will be distinguished from the largest existing Soviet tokamak—the T-10—by the significantly larger volume of plasma, the use of a powerful auxiliary heating system, and the use of superconducting toroidal-field magnets. The operating conditions in the T-15 will not result in "burning" of the fuel (hydrogen with small amounts of deuterium), but should be close enough to a burn to permit reliable extrapolation to such conditions.

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*A larger T-20 was described in the mid 1970s but appears to remain on the drawing board to date.

Inertial Confinement

The other technique for obtaining controlled fusion—inertial confinement—also has received attention in Soviet experimentation, with emphasis on the use of a pulsed reactor. In this technique, pellets of thermonuclear fuel are compressed radially by powerful laser beams or electron beams. The outstanding Soviet example is the Angara-1, which utilizes high-energy electron beams(84). In the pulsed reactor concept the resulting energy pulses heat a surrounding blanket of suitable structure such that a coolant passing through channels in the blanket will carry away heat for a thermodynamic power cycle or as a source for direct energy conversion (e.g., by MHD). The Kurchatov Institute has been developing the "Angara" electron-beam reactors, while the Lebedev Institute in Moscow has been working on a laser-beam reactor.

Commenting in July 1983, Academician N. G. Basov, director of the Lebedev Institute, observed that their main question regarding the problem of laser fusion was the selection of a type of laser for experimentation and for development of a commercial system of laser and reactor. Possible candidates that were being considered were high-power gas lasers (e.g., carbon dioxide lasers), excimer lasers (e.g., krypton-fluorine), and certain others (unspecified). Basov noted

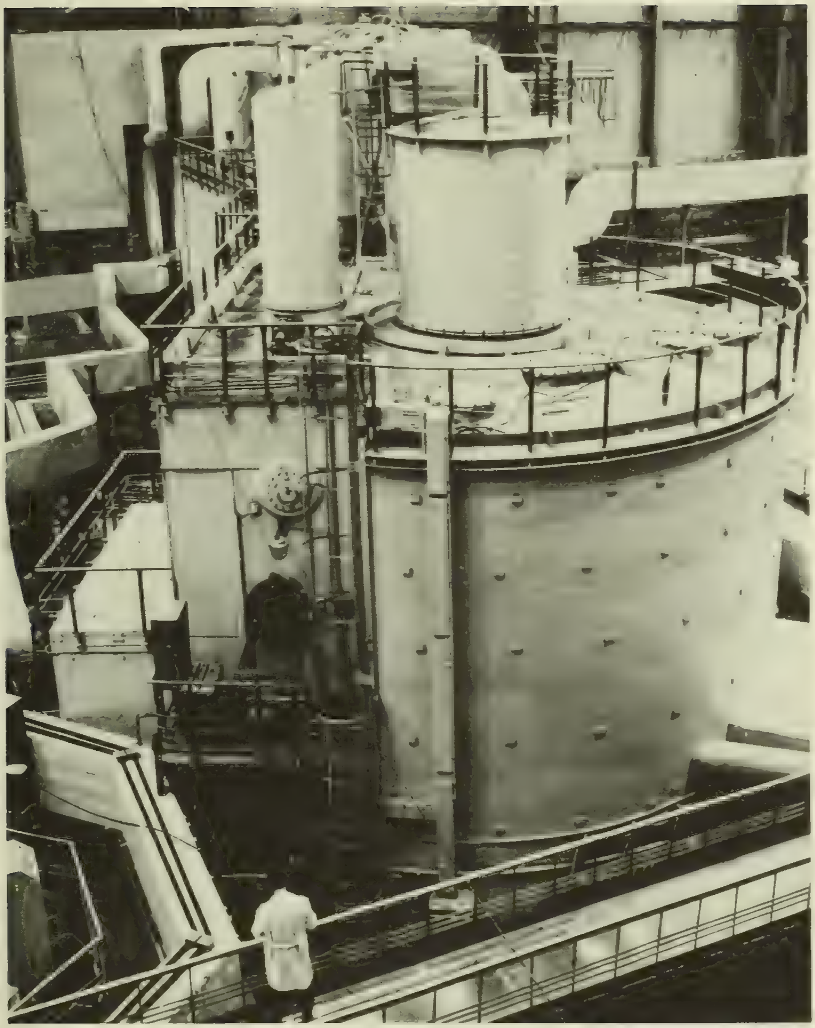

Figure 3 The Shevchenko Fast Reactor (photo credit: TASS from SOVFOTO)

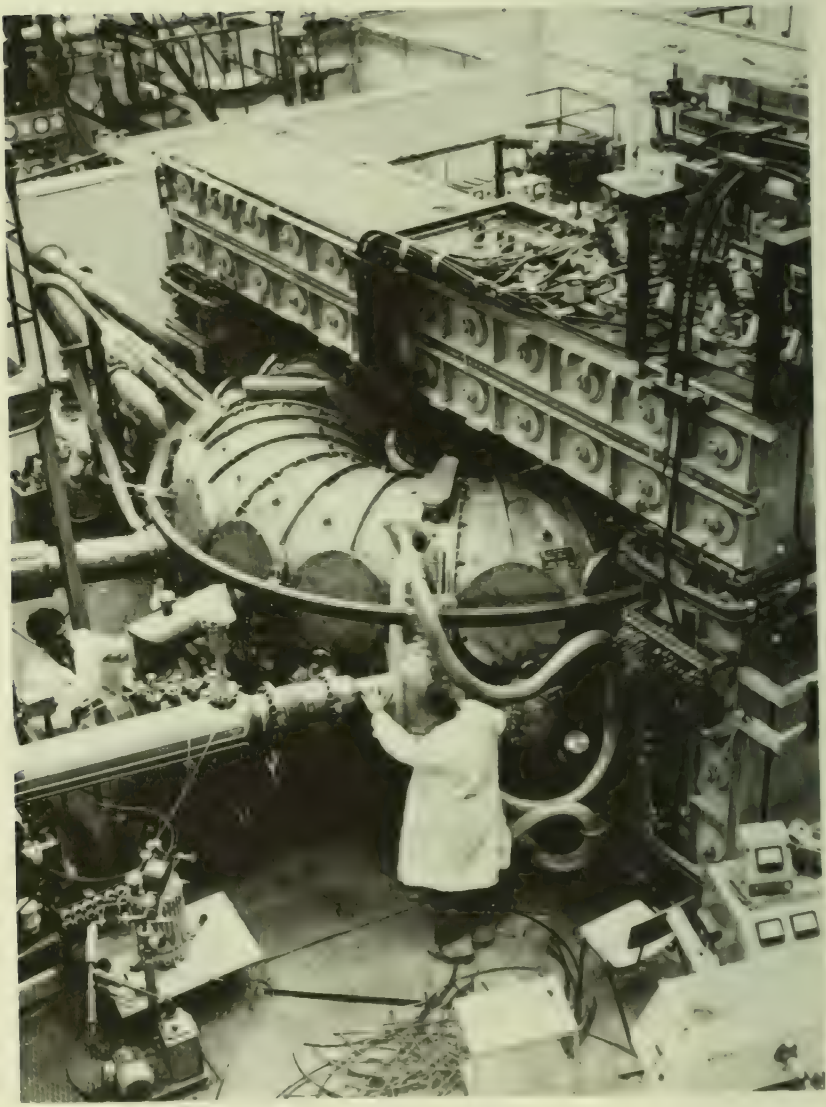

Figure 4 The Soviet "Tokamak-7" in Operation (photo credit: TASS from SOVFOTO)

that, in a parallel effort, engineering designs of pulsed thermonuclear reactors were being prepared—units that transform the energy of a thermonuclear microexplosion into a conveniently useful form of energy (electric power or process heat)(85).

As of late 1982, the Institute of Nuclear Physics in Novosibirsk was emphasizing experimental work with plasma-confinement schemes of the so-called "open" type for fusion reactors. The institute's founder, A. M. Budker (deceased), was one of the first to propose the "magnetic mirror" scheme of open confinement in the 1950s. Examples of open-type schemes under development at this institute are listed in table 4. D. D. Ryutov, deputy director of the institute, stated in 1982 that its staff hoped in the next two or three years to demonstrate the viability of the proposed methods on experimental units that would correctly model the conditions of plasma confinement in a fusion reactor(86).

Evaluation of the Soviet Fusion Program

Significance of the Effort. The USSR evidently believes that substantial benefits will accrue from its research on controlled thermonuclear fusion and is devoting considerable resources to this effort. However, as in the West, successful commercialization probably is several decades in the future.

Fusion reactors are envisioned as a source of cheap electricity, but they also might be used in the Soviet Union to produce plutonium in hybrid reactors. Because of the lessened radiation hazards expected with fusion reactors (in comparison with fission reactors), the plant siting problem is expected to be diminished.

The fragmentary evidence available suggests that Soviet support for fusion research has increased substantially over the past decade. On the basis of manpower figures, Robert Campbell has estimated that Soviet R&D expenditures on fusion amounted to some 66 million rubles in 1975, while comparable U.S. expenditures were reported to be $143.5 million(71). In preparing this estimate Campbell concluded that *total* Soviet *personnel* engaged in fusion research amounted to 11,000–12,000(71). Assuming that one-third of these are professional employees, Campbell's 1975 estimate would equate to 3,650–4,000 professionals.

In the case of magnetic fusion E. E. Kintner of the U.S. Department of Energy estimated in early 1982 that Soviet professional employment was approximately 4,000 and stable(87).* This would imply an annual operating budget outlay in excess of 60 million rubles per year for magnetic fusion.**

Although it is difficult to neatly fit together the estimates of Campbell, Kintner, and the present authors, we believe that Soviet expenditures on fusion research (both forms) have increased substantially since 1975.

While very significant progress has been made in controlled fusion research since about 1974, the most authoritative projection for achievement of a practical power-plant technology is sometime after the year 2000. It recently has been reported that some U.S. fusion researchers have reached a new milestone in achieving the required conditions for self-sustaining nuclear fusion. The Soviets claim to be near this milestone with their own equipment(80). When this "break-even" point is reached, more of the research effort can be concentrated on engineering development of a successful reactor concept. There are many reactor design problems that must be overcome before a prototype commercial reactor can be built. Many of these problems have been addressed for several years, but progress is slow. Eventually, available funding, which has been quite large, can be concentrated on the most promising design.

Time Frame for Development. In commenting on the Soviet-controlled fusion program in April 1983, Academician I. A. Glebov (see below) noted the further development of tokamak plasma chambers and the construction of other apparatus with auxiliary plasma heating. He indicated that this work is expected to be completed toward the end of the 1990s and, based on the comprehensive S&T program for the city of Leningrad up to the year 2005, entertained the possibility of building an experimental thermonuclear power station by the year 2000(90). This time frame is notably shorter than that projected by most experts in the field.

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*By contrast, Kintner estimated professional employment in magnetic fusion outside the Soviet Union to be United States—2,500; Europe—2,000; Japan—1,500(87).

**Estimated by tripling Kintner's figure to arrive at total employment and multiplying by average monthly compensation in Soviet "science and science services" in 1981 (183.2 rubles)(88); this product was multiplied by 12 to arrive at total annual compensation in magnetic fusion (26.4 million rubles). Because compensation is estimated to constitute about 40 percent of operating costs in Soviet science(89), this figure has been multiplied by 2.5 to arrive at estimated total operating expenditures of 66.0 million rubles. To arrive at total annual outlays on magnetic fusion, one would need to add to this expenditures for construction of new buildings and test facilities and equipment installed in new facilities. We have given a figure of 60 million rubles in the text because we believe that the monthly compensation figure used is inflated by the inclusion of social expenditures that are not proper to charge as R&D expenses: costs of housing subsidies, plus communal services and products.

In May 1983 Academician Ye. P. Velikhov, a vice president of the USSR Academy of Sciences, was quoted by Soviet sources as saying that work had reached a stage where it was possible to predict that it would be scientifically and technically possible to build an experimental thermonuclear fusion reactor by 1993 and that the first thermonuclear fusion power station should be in operation by the year 2000(91). Apparently this constitutes a Soviet goal.

Key Organizations and Personalities in Soviet Nuclear Programs

A large number of R&D facilities participate in the Soviet nuclear electrification program. A Soviet article in early 1983 placed the number of "lead" organizations in the fission and breeder reactor programs at 106(8). The key central state agency of Soviet nuclear electrification is the State Committee for the Utilization of Atomic Energy (GKAE), which has departments for atomic energy (Glavatomenergo) and thermonuclear fusion. The key GKAE research institutes are listed in table 5. Other institutes known to have a key role in atomic energy are affiliated with the USSR Academy of Sciences or its affiliated branches and republic-level academies; these also are listed in the table. A. M. Petrosyants, the current chairman of the GKAE, and A. P. Aleksandrov, the president of the USSR Academy of Sciences, are both strong advocates of nuclear electrification.

Two scientific councils coordinate R&D on nuclear electrification. One, which is headed by Aleksandrov, deals with fission reactor development, while the other deals with engineering problems of thermonuclear fusion and questions of plasma physics. I. A. Glebov, director of the All-Union Scientific Research Institute of Electrical Machine Building, presided over a meeting of the second council in early 1981, but it is not known if he is the council's chairman(92). (Later, in April 1983, it was reported that Glebov also had been appointed chairman of the presidium of the recently established Leningrad Research Center of the USSR Academy of Sciences. Glebov

Table 5 Key Organizations and Personalities Engaged in Nuclear Energy R&D

Organization (name, subordination, and location)	Area
Thermal Fission Reactors	
Institute of Atomic Energy imeni Kurchatov (IAE), GKAE, Moscow A. P. Aleksandrov, director Ye. P. Velikhov, deputy director L. I. Rudakov	Reactor concepts
Scientific Research Institute of Atomic Reactors (NIIAR), GKAE, Dimitrovgrad V. A. Tsikanov, director	Fuel, materials, and equipment testing
Scientific Research and Design Institute of Energy Technology (NIKIET), GKAE, Moscow N. A. Dollezhal, director (probable) I. Ya. Yemelyanov, deputy director Yu. I. Koryakin	RBMK reactors
OKB "Gidropress," GKAE, Podolsk	VVER reactors
Breeder Reactors	
Physical-Energetics Institute (FEI), GKAE, Obninsk O. D. Kazachkovskiy A. I. Leypunskiy	
Scientific Research Institute of Atomic Reactors (NIIAR), GKAE, Dimitrovgrad	
Thermonuclear Fusion	
Institute of Atomic Energy imeni Kurchatov (IAE), GKAE, Moscow	Magnetic confinement
Physical-Technical Institute imeni Ioffe (FTI), AN SSSR, Leningrad	Magnetic confinement
Physical-Technical Institute, AN UkrSSR, Kharkov	Plasma physics
Physical-Technical Institute, GKAE and AN Georgian SSR, Sukhumi	Plasma physics
Institute of Nuclear Physics (IYaF), SO AN SSSR, Novosibirsk	Magnetic and inertial confinement
Scientific Research Institute of Electrophysical Apparatus imeni Yefremov (NIIEFA), GKAE,	Fusion equipment design

Table 5 (continued)

Organization (name, subordination, and location)	Area
Leningrad V. A. Glukhikh, director	
Physics Institute imeni Lebedev, AN SSSR, Moscow N. G. Basov, director	Inertial confinement

was also identified as chairman of the USSR Academy of Sciences' interagency coordinating council in Leningrad[93]).

The key institute in the Soviet nuclear electrification program is the Institute of Atomic Energy imeni Kurchatov (IAE) in Moscow. The first Soviet-controlled fission chain reaction was achieved there in 1946. Development of the first Soviet atomic bomb also was carried out there. IAE provided the scientific leadership in the development of the VVER- and RBMK-series fission reactors and is the USSR's main fusion research center.

Fission reactor engineering talent appears to be centered in the Scientific Research and Design Institute of Energy Technology (NIKIET) (for the RBMK-series reactors), which evolved from a group that was at IAE before 1952, and the little-publicized OKB "Gidropress" in Podolsk (for the VVER-series reactors). NIKIET participated in the design of the early water-graphite reactors installed at the USSR's first NPS at Obninsk; more recently, NIKIET designed a VK-500 (500 MW) boiling-water reactor for the cogeneration of heat and electricity.

A fourth major fission research facility is the Scientific Research Institute of Atomic Reactors (NIIAR) at Dimitrovgrad. NIIAR conducts tests of equipment designed for NPS's and has a large facility for the analysis of nuclear fuels and materials for VVER and RBMK reactors.

The Physical-Energetics Institute (FEI) is believed to be the leading breeder reactor research facility in the USSR. Its early involvement with water-graphite reactor research, which led to the AMB-series reactors installed at the Beloyarskiy NPS, ended in the late 1960s. The BN-350 at Shevchenko and the BN-600 at Beloyarskiy were designed by FEI. (NIIAR also supports the breeder program by testing equipment, fuels, and materials on its BOR-60 experimental breeder reactor.)

The key institutes in Soviet fusion research are IAE (reactor concepts) and the Institute of Physics imeni Lebedev (laser development), both in Moscow. The key supporting technologies being developed here are plasma containment techniques, superconducting magnet design, pellet design, high-energy laser systems, chamber first-wall materials, blanket structures, and appropriate direct conversion techniques. Ye. P. Velikhov, a deputy director of IAE, appears to be the chief of the Soviet fusion program.

The Scientific Research Institute of Electrophysical Apparatus imeni Yefremov (NIIEFA) in Leningrad, directed by V. Glukhikh, has become the leading Soviet facility in the design and development of controlled fusion reactors (for construction and testing at other Soviet facilities). The institute has been instrumental in the construction of both magnetic-confinement and inertial-confinement reactors, including the Tokamak-15 and the Angara-5(94–97). The Institute of Nuclear Physics, in Novosibirsk, also is an important facility in the Soviet-controlled fusion program(98, 99).

The Soviet program for nuclear electrification appears to have the full support of the Soviet government, including the Central Committee of the Communist Party, the Council of Ministers, Gosplan, the State Committee on Science and Technology, and the Ministry of Power and Electrification. The efforts of the GKAE and its facilities are very well funded. With such support and a competent cadre of scientists and engineers, there is every reason to believe that the Soviets will continue to make progress in nuclear technology.

Chapter 4 The Production of Crude Oil and Arctic Gas

Oil and natural gas have become increasingly important in the Soviet fuel-energy balance, rising from 51.3 percent of total Soviet energy production in 1965 (measured in tons of standard fuel) to 66.5 percent in 1975 and 74.4 percent in 1983(1). These fuels not only support the growth of the Soviet economy, but also are exported, generating much-needed foreign exchange.

The Tenth Five-Year Plan called for further increases in the production of these energy sources, with extraction of crude oil (including gas condensate) to rise from 491 million metric tons (m.t.) in 1975 to 620–640 million m.t. by 1980, and gas production to increase from 289 billion cubic meters (m^3) in 1975 to 400–435 billion m^3 by 1980. (See also appendix A, items 1.b and 1.d.) The Soviet Union did expand the production of both of these fuels substantially during this period and met the goal for natural gas, but not the target for oil. In 1980 natural gas production reached 435 billion m^3—the upper end of the plan range, and over 50 percent more than in 1975. However, production of crude oil and gas condensate reached only 603 million m.t. in 1980(1). Nevertheless, it should be noted that the USSR registered an increase in oil production of almost 23 percent between 1975 and 1980 and maintained its position as the world's leading producer of oil.

The draft of the Eleventh Five-Year Plan (1981–85) calls for additional growth in the production of these fuels. The natural gas target is set at an ambitious 600–640 billion m^3 by 1985, while output of oil and gas condensate is to reach 620–645 million m.t.—the level originally sought for 1980(2). (See also appendix B, items 1.b and 1.d.)

Production of oil and natural gas has continued to rise during the initial years of the Eleventh Five-Year Plan, but the growth of oil production has been slow, while the natural gas sector has continued to advance robustly. In 1983 oil production reached 616 million m.t. and gas production was 536 billion m^3, both setting national records(3). Gas output continued to rise in 1984 (to 587 billion m^3), but oil production fell by 0.5 percent (to 613 million m.t.), perhaps marking the beginning of the CIA-predicted decline(4). As a result of these changes, natural gas has come to account for an even higher percentage of total Soviet energy production (31.1 percent in 1983, measured in standard fuel), but oil's share has declined (to 43.3 percent in 1983), falling below its share in 1975 (44.7 percent)(1). This pattern is almost certain to continue for the next few years.

Part of the production needed to meet Eleventh Five-Year Plan goals will come from traditional producing areas west of the Urals where production from existing oil and gas wells is continuing, deeper drilling is being carried out, and enhanced recovery techniques are being introduced in old oil fields. But if output of oil and natural gas is to be sustained and even increased, large production gains must be made in the new producing areas of Western Siberia. During the Tenth Five-Year Plan annual extraction of crude oil and gas condensate was to increase by 149 million tons, all of which was to come from Siberia. Annual extraction of gas during the same period was to increase by 146 billion m^3, 142 billion of which was to come from eastern regions(5). Eighty percent of the increased production of gas was to come from the northern part of the Tyumen region during the Tenth Five-Year Plan. But in the current five-year period (1981–85), the entire national increase is to come from this region(6).

This increased reliance on Western Siberia for oil and northwest Siberia for natural gas has forced Soviet oil and gas enterprises to operate in progressively harsher environments. The problems encountered with gas pipeline construction in the Arctic are indicative of the problems of any development activity under the adverse conditions of the area. Supply problems have been severe. The navigation season is short and port facilities are limited. Needed railroad construction is either behind schedule or postponed. As an example, *Pravda* reports that it took the gas ministry four years to arrange for the construction of a bridge over the Bolshaya Kheta River. During this period freight was unloaded on one shore and reloaded after crossing to the opposite shore(7).

The push for additional oil and gas has also forced the Soviets to drill deeper into the earth. As a result, the average depth of all wells drilled has increased from 1,590 meters in 1956 to 1,880 meters in 1965 and 2,020 meters in 1976(8). In exploratory drilling the average depth of wells has increased from 1,928 meters in 1960 to 2,775 meters in 1975 and 2,797 meters in 1978(9).

The quest for new oil and gas production has challenged Soviet technology as geological exploration has pushed farther into new areas of Siberia, into the Arctic, offshore, and to greater depths, and as production efforts have followed into these difficult environments.

The purpose of this chapter is to explore Soviet R&D efforts in five subject areas that will be important to Soviet success in future production of oil and gas: (1) geochemical prospecting, (2) drilling technology, (3) enhanced recovery of petroleum, (4) offshore technology, and (5) pipeline transport of Arctic gas.

Geochemical Prospecting*

Introduction

Soviet ability to produce energy from oil, natural gas, coal, uranium, shale, and even geothermal sources rests on an accumulated store of geological knowledge. Since new energy resources must be located and studied years before they can be developed commercially, it is advisable that geological prospecting precede attempts to develop energy resources by a sufficient number of years so that bottlenecks will not develop. This logic should be particularly compelling in a country that aspires to have a planned economy.

Therefore, it is not surprising that the Soviet Union has included geological prospecting in its five-year plans. As can be seen from item 1.g of appendix B, the draft main directions for the Eleventh Five-Year Plan include calls for (1) efforts to find additional reserves of oil, natural gas, and condensate in a number of areas of Siberia, Central Asia, the Kazakh SSR, offshore, and in traditional producing areas; (2) attempts to locate more deposits of oil shale and coal; and, (3) efforts to find raw materials to support nuclear power. A strong concern about geological prospecting is also evidenced by frequent references contained in main directions for lower levels of the planning structure (see appendix C) and in the scientific problem councils that have been formed (see appendix D).

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*In preparing this section, the authors have benefited from a previous Battelle study(10).

The draft main directions for the national economy also call for improvements in the equipment used in the geological prospecting and wider use of "progressive geophysical and geochemical methods" in order to raise the quality and economic efficiency of prospecting (see appendix A, item 1.g).

Geochemical prospecting is a method for locating deposits of minerals and hydrocarbons through chemical analysis of samples of rocks, soils, vegetation, streams, groundwater, ocean waters, and sediments. As such, it constitutes an application of "geochemistry," the science dealing with the chemistry of the earth. Geochemical samples are analyzed in order to directly detect a mineral or hydrocarbon being sought, or some other element or compound associated with the desired substance. The "indicator" element that provides a clue to the presence of the deposit sought is frequently one that is mobile and is expected to migrate away from the desired deposit in a predictable fashion. Through the detection of anomalies in the concentration or pattern of an element, geochemists may be able to detect the presence of a desired deposit that is located well below the surface of the earth or miles from the site of the samples. Geochemical techniques are frequently employed in conjunction with traditional geological surveys, geophysical methods (seismic, radioactive, magnetic, electromagnetic, and gravimetric surveys), geobotany, and biochemical methods.

The Soviet Union introduced modern geochemical prospecting techniques in the early 1930s and still accounts for approximately half of all geochemical exploration activity in the world. Soviet geochemical research efforts that are directed toward improving the effectiveness of these techniques are under way at a number of institutes scattered across the USSR. Some of these efforts are described below.

Geochemical Prospecting for Oil and Gas

Introduction. An unusual feature of Soviet R&D efforts on energy is the strong emphasis on geochemical prospecting for energy sources, including oil and gas. A common Western view is that geochemical exploration has little relevance to hydrocarbons and is used mainly in connection with prospecting for metals. It is clear that most Soviet R&D on geochemistry does not deal with oil or natural gas. On the other hand, there has been a modest but steady stream of publications dealing with this subject since Vladimir I. Vernadskiy began lecturing on the subject in the 1920s. As one modern measure, it might be noted that almost two out of every three issues of *Geokhimiya,* the leading Soviet journal on geochemistry, contain major articles, notes, or symposia information relating to geochemistry of oil and natural gas. Over the past several decades this continuing flow of research and publication has created a substantial pool of Soviet knowledge about how to search for oil and gas by using geochemical methods.

Research Activities. Soviet publications have dealt with a number of aspects of the geochemistry of oil and gas, including: isotopic composition of groundwaters associated with oil and gas deposits (especially the water-oil contact zone)(11, 12, 13); distribution of sulfur in various types of oil(14); hydrocarbon composition of oil during the processes of biodegradation and catagenesis (15, 16); and isotopic composition of carbon in various types of oil and natural gas (17, 18).

Two types of studies have been especially prominent. First are isotopic studies of hydrogen, oxygen, and carbon (involving deuterium, oxygen-18, and carbon-13)(11, 12, 17, 18). Second are investigations of changes in the hydrocarbon composition of oil and gas deposits in the course of various processes (water flooding, biodegradation, catagenesis, and migration of oil)(13, 15, 16).

Although most of the geochemical research involving oil and gas is directed ultimately at ways of locating new deposits of hydrocarbons, some R&D has other applications. In 1982, for example, specialists at two institutes developed a geochemical method for monitoring the movement of the water-oil contact zone during water flooding of an oil field(13).

In the course of these investigations, researchers have examined oil and gas samples from a number of regions stretching across the USSR, including: Dnepr-Donets Oil and Gas Province (e.g., the Pripyat Depression)(11); Volga-Urals Oil and Gas Province (e.g., Tatar ASSR, Perm-Kama River)(14, 15, 16, 17); Transcaucasian Oil and Gas Province (e.g., Duvannyy-More, Sangachaly-More)(13); Timan-Pechora Oil and Gas Province (19, 20); West Siberian Oil and Gas Province (11, 12, 14); East Siberian Oil and Gas Province (e.g., Irkutsk Amphitheater)(14); and Far East Oil and Gas Province (e.g., Kamchatka)(18).

Key Organizations and Personalities. Research activities aimed at improving geochemical methods for locating oil and natural gas are in progress at more than than two dozen institutes. Based on a count of recent publications, the most active organizations appear to be the Institute of the Geology and Development of Fossil Fuels (IGIRGI), the All-Union Scientific Research Geological Prospecting Petroleum Institute (VNIGNI), the Institute of Geochemistry and Analytical Chemistry imeni V. I. Vernadskiy, and the Institute of Organic and Physical Chemistry. Names of key researchers at these and several other institutes are listed in table 6.

Two researchers have been especially active in this field—V. A. Chakhmakhchev of IGIRGI and E. M. Galimov of the Vernadskiy Institute, both located in Moscow.

V. A. Chakhmakhchev has been publishing since at least 1969 and has been associated with IGIRGI since that year. A central theme of much of his work has been changes in the hydrocarbon composition of oil in the course of migration(20). He has investigated this and other problems (e.g., catagenesis of oil) by studying the microelements found in oil, such as vanadium, nickel, cobalt, copper, chromium, aluminum, and zinc, using techniques such as atomic-absorption spectrophotometry(19, 20).

The other outstanding scholar in geochemical prospecting for oil and natural gas is Erik Mikhaylovich Galimov of the Vernadskiy Institute. Galimov has been conducting geochemical research relevant to oil and gas prospecting since at least the mid-1960s and has authored numerous articles and books, including *Carbon Isotopes in Petroleum Geology* (1973) and *The Nature of Biological Fractionation of Isotopes* (1981). As the reader may suspect from the second title, E. M. Galimov's work is not limited to applied research in oil and gas prospecting, but is broader in scope and has a heavy theoretical component. Nevertheless, a substantial portion of his work has dealt with specific petroleum deposits and has included recommendations on where to look for oil and gas. As an example, a 1975 carbon-isotope investigation of Mid-Caspian Sea deposits concluded: "the predicted Central Caspian Sea Dome is an especially promising oil and gas region that, being located at the divide between the indicated oil-generating zones, could itself be a large oil-accumulation

Table 6 Key Organizations and Personalities Engaged in Geochemical Prospecting for Oil and Natural Gas

- All-Union Scientific Research Geological Prospecting Petroleum Institute (VNIGNI)
  - A. Z. Koblova (Perm)
  - M. G. Frik (Perm)
  - V. A. Lobkov (Leningrad)
- Institute of Geochemistry and Analytical Chemistry imeni V. I. Vernadskiy, AN SSSR, Moscow
  - E. M. Galimov
- Institute of the Geology and Development of Fossil Fuels (IGIRGI), AN SSSR, Moscow
  - V. A. Chakhmakhchev
  - I. F. Lositskaya
  - S. A. Punanova
- Institute of Organic and Physical Chemistry, Kazan Filial of AN SSSR, Kazan
  - G. P. Kurbskiy
  - V. V. Abushayeva
  - A. I. Bogdanchikov
- Institute of Petroleum Chemistry, SO AN SSSR, Tomsk
  - O. V. Serebrennikova
  - V. I. Titov
  - V. N. Burkova
  - L. V. Ryadovaya
- Siberian Scientific Research Institute of Geology, Geophysics, and Mineral Resources, Tomsk Department
  - S. I. Golyshev
  - V. G. Ivanov
  - A. V. Cherepnin

zone not exceeded in terms of possible reserves by the Mangyshlak or Eastern Ciscaucasian oil regions"(21).

A notable aspect of Galimov's work has been his coauthorship with researchers at other organizations, including: All-Union Scientific Research Geological Prospecting Petroleum Institute (VNIGNI), Kama Department, Perm; All-Union Scientific Research Institute of Gas, Moscow; Institute of Oceanology, AN SSSR, Moscow; Laboratory of Geology of Foreign Lands, USSR Ministry of Geology; Moscow Institute of the Petrochemical and Gas Industries. The effect of this coauthorship probably has been to link the geochemical expertise of Galimov and the Vernadskiy Institute with the geological knowledge of specific regions or types of deposits embodied in these other institutes. A prime example of this is a 1983 article in which Galimov teamed up with researchers at the Kama Department of VNIGNI (in Perm) to conduct a carbon isotopic study of seven types of oil from the Perm/Kama River area(17).

Much of the publication activity in this field is theoretical in nature and is centered at institutes subordinate to the USSR Academy of Sciences, which is oriented toward basic research. The reader will note, for example, that two-thirds of the institutes listed in table 6 (the most active organizations in terms of publications) are subordinate to the USSR Academy. As a result, the full effect of Soviet work in this field may be evident only over a period of years as new methods move from Academy laboratories to field applications.

Geochemical Prospecting for Other Energy Source Materials

Twelve institutes are conducting studies that should aid the USSR in locating additional supplies of uranium. The most active of these appear to be the All-Union Scientific Research Geological Institute, Moscow State University, the Institute of Precambrian Geology and Geochronology, and the Vernadskiy Institute.

Furthermore, at least seven facilities have been involved in geochemical studies that should be useful in developing other energy sources. R&D activity related to coal or shale oil has been in progress at the Institute of Mineralogy, Geochemistry, and Crystal Chemistry of Rare Elements; the All-Union Scientific Research Institute of Nuclear Geophysics and Geochemistry; Voroshilovgradgeologiya Trust; and Tadzhik State University. Studies of the geochemistry of volcanoes, geysers, or other sites that could be used for geothermal power have been conducted at three institutes affiliated with the USSR Academy of Sciences: the Institute of Volcanology of the Far East Scientific Center; the Institute of Geochemistry of the Siberian Division; and the Institute of Chemical Physics.

Evaluation

There are indirect indications that geochemical prospecting for oil and gas (and other energy source materials) enjoys substantial support in the USSR. Geochemical prospecting is mentioned explicitly in the draft main directions for the national economy (appendix B, item 1.g) and in the "Scientific Problems and Directions in Geology, Geophysics, Geochemistry, and Mining" (appendix C, item 4.d). There is a "Scientific Problem Council on Problems of Geology and Geochemistry of Oil and Gas" under the USSR Academy of Sciences and this problem council is headed by a prominent and influential person—A. A. Trofimuk, the deputy director of the Siberian Division of the USSR Academy of Sciences and director of the Siberian Division's Institute of Geology and Geophysics. Personnel at thirty different institutes have contributed to publications dealing with geochemical prospecting. Since 1956 the Soviets have been devoting an entire journal (*Geokhimiya*) to geochemistry, and in 1971 the First International Geochemistry Congress was held in Moscow(22). Finally, the Soviet Union has established itself as the world leader in geochemical prospecting work and, in a 1976 Western review, was judged to be well ahead of its nearest competitors, Canada and the United States(10).

No published figures were found on the amount of funds or manpower devoted to geochemical prospecting for oil and gas. However, one can form estimates of manpower and funding from the volume of publication activity. Over the ten-year period from 1974 to 1983, sixty-eight individuals were authors or coauthors of published articles on geochemical aspects of oil and gas. Over the shorter period 1980–83, forty-seven authors were represented by publications. Allowing for professional employees who do not publish, it seems reasonable to assume that there were at least sixty professional employees conducting research on the geochemistry of oil and gas during this four-year period. Using the reasoning employed in chapter 3 ("Evaluation of Soviet Fusion Programs"), this implies total employment of 180 (allowing for support personnel) and a total operating budget of over 1 million rubles (180 × 190.9 rubles × 12 months × 2.5)(1). This pales by comparison with the R60 million operating budget estimated for magnetic fusion (see chapter 3). Nevertheless, this is not an insignificant amount of effort, given the nature of the field, and it would not be surprising if geochemical prospecting methods made a contribution to Soviet efforts to find oil and gas in the years ahead. In short, geochemical prospecting must be judged to be one of the strengths of Soviet efforts in geology and geological prospecting.

Drilling Technology

Introduction

The technology for drilling exploratory and production wells for oil and natural gas encompasses a number of devices and techniques, including drilling and core-sampling tools, drill pipe, casing, drilling rigs, and drilling muds, as well as procedures for combining and operating equipment in an optimal fashion.

Western commentators have been generally critical of Soviet drilling technology. Arthur Meyerhoff, a petroleum geologist who has served as a consultant to the USSR Ministry of the Oil Industry, has reported that it takes only thirty-four days to drill to a depth of 10,000 feet in the United States, but fourteen months in the Soviet Union(23). In 1978 Meyerhoff rated Soviet drilling technology as "28 to 35 years behind the West," on the average(24). A 1977 study by the CIA judged Soviet drill bits to be "grossly inferior" to those produced in the United States(25), while Robert Campbell's 1976 study argued that "weaknesses exist in all elements of Soviet drilling technology —quality of bits and drill pipe, mud technology, and in the organization and supply of drilling operation"(26).*

The Soviet Union is not prepared to make such critical statements about its own technology, but a number of problems have been recognized and efforts are under way to correct these problems, as evidenced by the inclusion of the following statement on drilling technology in the draft main directions for the Tenth Five-Year Plan: "Improve the efficiency of drilling work. Reduce by 25 to 30 percent the periods for well drilling by increasing drilling speeds; by introduction of universal drilling rigs, new types of bits, bottom-hole engines, drilling fluids, high-strength casing and drill pipe; and by improvement of the organization of work and application of progressive methods of assimilating wells." (See appendix A, item 1.b.)

Such improvements will be particularly important in the 1980s because of Soviet plans to engage in more "superdeep" drilling (i.e., drilling below 4,500 meters). Soviet experts estimate that the USSR has some 3.3 million km^2 of sedimentary mantle at depths of 4,500 to 7,000 meters. During the Tenth Five-Year Plan a total of 225 prospecting and 113 exploratory wells were drilled below 4,500 meters; in the latter part of the 1980s, plans call for 160 to 180 superdeep wells per year (roughly 2.5 times the average annual rate achieved in the Tenth Five-Year Plan). As of August 1983 the deepest oil deposit found was in the northern Caucasus at a depth of 5,612 to 5,800 meters(29).

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*Some Western criticisms of Soviet drilling technology are grossly exaggerated. As an example, Goldman has stated: "It is true that USSR factories produce more drill bits per year than American factories, but they have only two varieties"(27). As will become evident from this section, the first statement is true, but the second is not. In 1977 the USSR produced approximately 150 varieties of rolling cutter bits alone(28).

The discussion that follows examines the turbodrill, drill bits, drill pipe, and drilling rigs. This list of topics is not exhaustive but includes the most serious drilling problems to which Soviet researchers are devoting their efforts.

The Turbodrill

Considerable attention has been given to the Soviet turbodrill as a source of strength and weakness in the development of Soviet oil and gas production. In contrast to the United States, which relies primarily on rotary drilling, the Soviet Union has emphasized the turbodrill. Turbodrilling is an approach to drilling in which the drill bit is turned by a fluid-driven downhole turbine, rather than by the rotation of the drill string (rotary drilling). In turbodrilling, the mud pumped to the bottom of the hole thus serves two functions: transmission of power to the drill bit and removal of cuttings(30).

A major reason for this Soviet decision initially was the difficulty with the quality of drill pipe and tool joints. By adopting a system in which the drill string was not rotated, the Soviets were able to reduce stresses on the drill string and thereby to increase bit penetration rates more than would have been possible with Soviet rotary drilling technology(26). In addition, the turbodrill proved to be well suited to directional drilling, a circumstance that has permitted the Soviets to drill a number of wells from a single drilling site. This opportunity for clustered drilling has helped the Soviets in offshore development of the Caspian Sea and has facilitated production in Western Siberia where sand islands must be built in the swampy land before drilling can begin(31). Since the construction of offshore platforms and sand islands are expensive site-preparation procedures, it is advantageous if these costs can be spread over a number of wells instead of just one.

Against these advantages, there have been several disadvantages of the turbodrill. In its traditional form the turbodrill was characterized by high rpm and low torque and was operated with light weight on the bit. This combination gave relatively rapid penetration rates, especially in hard deposits(26, 32). Unfortunately, this combination also led to rapid bit wear and, consequently, to a reduction in the number of meters that could be drilled with each bit. In short, while operating, the turbodrill was capable of very rapid penetration rates, but bits had to be changed frequently, resulting in more and more time devoted to "tripping" (removing the drill stem from the hole, changing the bit, and reinserting the drill stem). With an increase in the average depth of wells over the years, the time requirements for tripping have increased disproportionately.

Other disadvantages of the turbodrill in comparison with rotary drills should be noted. First, the turbodrill does not tolerate heavy weights on the bit and hence cannot be used in a high-pressure, forced regime as can the rotary drill(33). Second, the turbodrill requires more frequent maintenance when operated in higher temperature formations(33). Finally, the efficiency of the turbodrill deteriorates when it is used with drilling muds of high specific gravity and viscosity (e.g., in strata having high formation pressures, where such muds are called for)(30).

Several approaches to the rpm/torque problem have been considered. First, one could attempt to design a turbodrill with lower rpm and higher torque. Second, one could improve the life of drill bits (e.g., by using diamond bits). Third, one could replace turbodrilling with rotary drilling, at least below a certain depth. All three approaches have been considered.

There is no evidence to suggest that turbodrilling is about to disappear from the Soviet scene. Campbell's 1976 study reported that the turbodrill's share of total drilling dropped from about 85 percent in the early 1960s to about 74 percent in 1970, but a 1979 article indicated that the percentage had risen back to about 80 percent (26, 34). Rotary drilling has been introduced in certain areas where local conditions (e.g., formation pressures or temperatures) provided an especially strong rationale for it. As an example, in Stavropol Kray where well depths already were more than 3,000 meters and temperatures of over 130°C were being encountered, rotary drilling was heavily pushed in the early 1960s and had completely displaced turbodrilling by 1976(33). And in the Bashkir ASSR, where the turbodrill's share fell from 92 percent in 1971 to 82 percent in 1980, a further decline to 50 percent was anticipated by 1985(35).* Nevertheless, we expect the turbodrill to remain the leading drilling tool in the Soviet Union during the 1980s.

The turbodrill has persisted for a variety of reasons. For one thing, many of the problems that initially made turbodrilling more attractive than rotary drilling remain. As an example, when turbodrilling began to be emphasized in Stavropol Kray, problems were encountered with existing ground equipment, and "Uralmash" and VNIINeftemash (All-Union Scientific Research Institute of Petroleum Machine Building) were called upon to design and produce new swivels and rotors. In addition, the number of breaks in drilling tools increased sharply because of the added mechanical stresses encountered in rotary drilling. Until these problems were overcome, downtime was canceling all of the operating advantages of rotary drilling in Stavropol Kray(33).

Another reason for the persistence of the turbodrill is not technological or economic, but emotional—the Soviets pioneered in turbodrilling technology, take great pride in it, and are likely to push for further refinements in this technology rather than switch to rotary drilling in a big way.

What seems to be emerging is a pragmatic approach in which a variety of drilling technologies will be made available and drillers will be encouraged to select the equipment that is most economically advantageous for the formations and depths to be drilled. An excellent statement of this approach was presented in a 1983 article by Ioanesyan** and others from VNIIBT (discussed below). The authors present a number of rules of thumb for choosing between rotary and turbine drilling (e.g., turbodrilling is not suitable for drilling vertical wells from the surface in rock that is soft or sticky-plastic)(36).

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*It is interesting to note that the chief beneficiary of the decline of turbodrilling in the Bashkir Autonomous Republic may be electric drilling rather than rotary drilling. In that area, where the electric drill is favored for deep drilling in complex geological conditions, electric drilling may rise to 21 percent of the total by 1985, more than doubling its share in the total from the 1980 level. Rotary drilling, by comparison, will move up to only 10 percent of the total(35).

**This is not the famous R. A. Ioannesyan, and the differences in spelling suggest that the two are not related.

In short, the evidence suggests that the Soviets have decided to continue to make incremental improvements in the turbodrill rather than take the radical step of switching to an entirely new technology (rotary drilling). Having made this decision, the Soviets have devoted considerable effort to improving the performance of the turbodrill by lowering its rotation speed and increasing torque(26). They also have sought to determine the optimum equipment and drilling parameters for drilling individual wells and have begun to consider the application of computers to such optimization problems(37).

Drill Bits

Introduction. The Soviet effort to develop oil and natural gas deposits is hampered by a number of difficulties associated with drill bits. The basic problem is that the Soviet Union has emphasized quantity rather than quality in drill bit manufacture. According to spokesmen for Dresser Industries, the USSR has a larger drill bit production capacity than any other country in the world(38). More specifically, a 1977 CIA study reported that the Soviet Union then produced approximately 1 million rock bits of all sorts annually—over twice the number manufactured in the Western world each year (about 400,000)(25). Yet in 1975 the Soviet Union's Ministry of the Oil Industry, which accounts for most Soviet drilling, drilled less than 12 million meters, while the United States oil industry drilled 53 million meters(39, 40). Taken together, these figures suggest that the number of meters drilled per Soviet bit must be much lower than for a U.S. bit—perhaps only one-fourth as much.

A consequence of the low meterage per Soviet drill bit is an inordinate amount of rig time devoted to "tripping"—the raising and lowering of the drill string associated with changing bits (or other downhole equipment). As noted earlier, the problems of rapid wear of bits and excess tripping have been accentuated by the use of high rpm turbodrills.

Much attention has been given to Soviet attempts to import Western drill bit manufacturing technology, the most famous of which has involved a $144-million contract with Dresser Industries of Dallas for technology to be incorporated into a new drill bit manufacturing facility being built at Novokuybyshevsk on the Volga River(38). This factory originally was scheduled to open in 1981, but construction was delayed by a variety of factors and Dresser's export license was revoked in late 1980 by the U.S. government in retaliation for the Soviet invasion of Afghanistan (38, 41). In spite of these problems, the plant was completed and has been operating for several years(42).

Much less has been written about the extensive efforts of the Soviet R&D community to provide the nation with better drill bits employing Soviet technology. The balance of this subsection examines some of these efforts.

Diamond Bits. Given the nature of the turbodrill and the attendant problems of rapid wear of bits and frequent tripping, it has seemed logical to Western observers that the Soviets should make greater use of diamond drill bits, at least for deeper drilling. According to one source, 1970 experiments showed that diamond bits lasted for an average of fifty-six meters(26). There are more recent reports of diamond bits that lasted much longer—as much as 350 to 410 meters(43). In addition, diamond bits are reported to be less sensitive to the nature of drilling muds than are rolling cutter bits(32).

Natural diamond bits have been employed in drilling deep oil and gas wells in the Soviet Union for some thirty years, but they have never accounted for a very large share of meterage drilled(44). The use of diamond bits has expanded rapidly in recent years, rising from 1 percent of total meters drilled in 1968 to 2 percent in 1972 and 4 percent in 1976(26, 43). In absolute terms, this represents a 470 percent increase, from about 111,000 meters drilled with diamond bits in 1968 to about 635,000 meters in 1976(26, 31). Nevertheless, diamond bits still account for less than 5 percent of all meterage drilled at a time when the Soviets are under increasing pressure to exploit deep deposits of oil and gas.

No thorough analysis of the factors behind the slow growth of diamond bit drilling was found in the Soviet literature, but there are reasons to believe that the slow growth rate is due to economic as well as technical considerations. A 1978 article indicates that natural diamond bits are costly to produce in the USSR and are not well suited for drilling certain formations(44). On the technical side, one can speculate that diamond bits may not have functioned as well as would be expected because of the nature of the Soviet drilling equipment. Western texts on drilling indicate that diamond bits are prone to failure from vibration and that high rpm promotes vibration(45). This suggests that the early version of the turbodrill, which was characterized by high rpm, may not have been compatible with diamond bits. It is known that Soviet scientists have investigated the problem of vibration in diamond drilling(46), and Meyerhoff has witnessed instances in which drilling equipment experienced catastrophic vibration problems due to low-quality steel products and other deficiencies(24). In addition, diamond bits can be damaged by debris at the bottom of the hole—e.g., broken fragments of teeth from rolling cutter bits used to drill shallower depths(32). In view of the numerous reports on the low quality of Soviet bits, such fragments may be a common feature of Soviet drilling.

A technology for producing synthetic diamonds has been developed by the USSR Academy of Sciences' Institute of High Pressure Physics, and there are indications that bits employing synthetic diamonds will have a rational role to play in future Soviet drilling, particularly in deep drilling of hard sandstone formations. Industrial tests of artificial diamonds of the carbonado type were to begin in late 1978 or early 1979(44).

In time, synthetic diamonds may displace natural diamonds in Soviet drilling. As an example, the Grozneft Association, which is drilling relatively deep wells (87 percent have a designed depth of more than 4,500 meters), employs diamond bits of both types(47).

Rolling Cutter Bits. The favored bit for drilling oil and gas wells in the Soviet Union appears to be the rolling cutter bit: in late 1977 it was reported that 95 percent of production drilling and up to 87 percent of exploratory drilling was being carried out with such bits. In 1977 the USSR manufactured about 150 varieties (*tiporazmery*) of such bits(28).

A number of efforts are under way to improve Soviet drill bits. In 1979 N. A. Maltsev, the minister of the oil industry, indicated that Soviet scientific research institutes and design organizations had developed 122 varieties of bits of a new design that was suitable for low- and high-rpm drilling. About 75 varieties of these bits—which include types 1-AV, 1-AN, 2AN, and 3AN—were then being put into production(34).

Published information on tests of the series 1-AN bits indicates that they offer improved results in both low-speed rotary drilling and high-speed turbine drilling. These bits have three rolling cutters and a combination cutter support, with antifriction and sliding bearings. Because these bits have cutter supports that are more durable, the bits as a whole last longer. As an example, in tests of 1-AN-190 bits, the bits reportedly were able to cut 20 percent more meterage on the average, largely because of increased durability of the cutter supports. Operating costs per meter drilled can be reduced by 11–34 percent in comparison with ordinary bits, but the bits are sensitive to axial loads and the nature of drilling muds used with them. In addition, those reporting on test results for the 1-AN bits placed strong emphasis on the need to adhere strictly to State Standards in manufacture of the bits(48).

Application of Superhard Materials. The Soviets also are developing more durable materials for drill bits. As of 1977, about 30 percent of all bits produced in the USSR had hard alloy teeth in the rock crushing elements(28). In 1979 Maltsev reported that factories were beginning to produce parts for bits from steels that had undergone electroslag remelting and vacuum arc remelting(34).

But the most spectacular results have been reported from bits incorporating new superhard materials such as "slavutich." Slavutich, which was developed by the Ukrainian Academy of Sciences' Institute of Superhard Materials, is a special alloy that is so resistant to wear that it can replace forty to seventy conventional tricone bits or two to three diamond bits(44, 49). Testing has been under way since 1972 in the Azerbaydzhan SSR (especially in the drilling associations of Kaspmorneft), and individual bits are reported to have cut more than 1,100 meters in production drilling and 500 meters in exploratory drilling(49). The slavutich bits are evidently expensive and hence are not recommended for all depths or even for all types of formations. Tests have shown that the bits are cost-effective at depths from 2,000–2,500 to 5,000–5,500 meters, except where quartz sandstones occur. When used with high-speed turbodrills, it is claimed that operating expenses per meter drilled can be reduced by 27–51 percent. Based on the previous discussion, it can be assumed that much of this saving is due to a reduction of tripping. While slavutich bits are costly to manufacture, significant economies can be achieved by renovating used bits inasmuch as the latter still contain up to 75–80 percent of the original slavutich material(44).

By early 1980 slavutich bits were being manufactured at the experimental plant of the Institute of Superhard Materials(49). Renovation of used bits has been carried out at the Plant imeni Kirov in Baku(44).*

Evaluation. It appears unlikely that any single type of drill bit will completely displace one of its competitors in the near future. Comments by Soviet drilling foremen indicate that they wish to have available an assortment of bits and to be able to choose among standard tricone bits, diamond bits, and bits tipped with "slavutich," depending on depth and geological conditions (47, 51). As an example, one foreman who has been drilling offshore in the Caspian reported excellent results from using diamond bits in the interval 4,000–4,500 meters, reporting eighty-three meters per bit, whereas only eleven to thirteen meters could be obtained on the average from tricone bits under the same conditions(51).

It is evident that efforts to increase the number of meters drilled per bit have had some success. As an example, the Nizhnevolzhskneft Association reported an 81 percent increase in meterage per bit in production drilling from 1971 to 1976 (from 21.6 meters to 39.0 meters per bit) and a 41 percent increase in exploratory drilling (from 16.6 meters to 23.4 meters per bit)(52). In the Grozneft Association, hole made per bit increased by 17 percent from 1975 to 1978 (from 30.1 meters to 35.3 meters per bit)(47).

A 1983 research article indicates favorable results with the 295.3 SZ-GV rolling cutter bit, with an average of forty-six meters per bit in turbodrilling(53).

For the USSR as a whole, it is reported that the number of meters drilled per bit during the period 1971–75 increased by 31 percent in exploratory drilling and by 58 percent in production drilling(28). Similar increases have occurred since 1975: meters drilled per bit for all types of drilling increased by 42 percent between 1975 and 1978(54), and average meterage per bit in production drilling rose by 39 percent during the period 1976–78(34).

The reader should note the problems in interpreting such averages: since bit life varies among different types of bits, improving averages can be achieved by changing the mix of bits as well as by improving the quality of the individual types of bits. In addition, it is evident that the number of meters per bit for a particular type of bit varies with the method of drilling, the type of formation, and the depth being drilled. (For an example of the latter factor, see reference 53.) Because all of these factors are changing over time, it will be difficult for Western analysts to easily judge Soviet progress in improving the quality of drill bits.

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*The Plant imeni Kirov is one of twelve enterprises included in Soyuzneftemash (All-Union Industrial Association for Petroleum Industry Machinery) under the Ministry of Chemical and Petroleum Machine Building(50).

Finally, it is worth noting that during the Tenth Five-Year Plan the Soviet Union was to finish making its transition to the production of new drill bits that conform to international standards on nominal exterior diameters and thread sizes(28). Such a move should make it easier to combine imported Western equipment with drilling equipment produced in the USSR.

In spite of all these efforts, problems with drill bits have continued as the Soviets have moved into the 1980s. In August 1983 Academician Aganbegyan complained in *Pravda* that the quality of drill bits still was limiting drilling speed(55).

Other Drilling Problems

As Soviet exploration and production efforts have pushed into Siberia, the Arctic, and greater depths, increasing stresses have been placed on Soviet drilling equipment. Solutions to the problems created (and even the nature of the problems themselves) have been conditioned by the peculiarities of the Soviet economic system. As we hope to illustrate, environmental, technical, and "systemic" problems are often intertwined in a complex fashion.

As noted earlier, the average depth of Soviet oil and gas wells has been increasing, with a resultant deterioration of the economics of the turbodrill. Whether the Soviets respond to increasing depths by shifting to rotary drilling or by modifying the turbodrill, increasing depth places increasing stress on a variety of pieces of drilling equipment, including drill pipes, derricks, and hoists.

Soviet drill pipe has not been of high quality in the past and has not stood up well to these stresses. Specific quality problems that have been pointed out include delivery of pipe with angular rather than trapezoidal threads, failure to protect threads and joints from damage in shipment during feezing weather, and failure to make pipe resistant to corrosion and paraffin buildup. Poor-quality drill pipe in combination with frequent tripping has led to a number of accidents in which drill strings have simply broken while being raised or lowered, dropping the string into the hole. As an example, during a three-year period in the mid-1970s Glavtyumenneftegaz experienced one hundred drilling accidents attributed to poor-quality drill pipe(56). Because of such accidents, wells often are idled for weeks or months and sometimes are lost entirely. Such problems still were being reported in the Soviet press in the early 1980s. One group of drillers near Zardob in Azerbaydzhan found plant defects in 30 percent of the casings received from the Dnepropetrovsk Plant(58).* In August 1983 a *Pravda* article complained about the low quality of drill pipe being sent to Western Siberia(55).

Such supply problems are common in the Soviet Union and arise from a combination of factors, including genuine shortages of productive inputs and perverse incentives. Manufacturing plants frequently do not receive all of the materials, workers, and equipment needed to fulfill the output plans imposed on them. Because they cannot do the impossible, part of the shortage is passed on to their customers in the form of goods that are defective, are late, or are never shipped at all. Emphasis on crude quantity measures (e.g., tons of pipe produced or shipped) rather than quality or profits often robs the supplier of any incentive to meet the specifications of the order in anything but an approximate fashion. Because suppliers generally are assigned rather than selected by the customer, the customer must continue to deal with the supplier and frequently is unwilling to cause bad relations by using the legal remedies that are available in contract disputes.

The weak position of the customer in this system can be illustrated with a drill pipe example. As noted earlier, when the Stavropolneftegaz Association began to emphasize rotary drilling it encountered problems with the quality of drill pipe, which proved to be especially prone to failure in the upset part of the pipe near the threads. Drillers of the association concluded that the problem could be reduced by defectoscopic examination of the pipe and by reinforcing the weak part of the drill stem. But instead of imposing such requirements on the pipe manufacturer, which should have had a comparative advantage in undertaking these activities, the association took them on and built a special shop for the purpose. Reports on the association's experience do not even indicate a strong expectation that the manufacturer should have taken on these jobs(33).

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*Probably the Dnepropetrovsk Tube Rolling Plant imeni Lenin(57).

Other cases of customers (rather than suppliers) adapting to deficiencies of equipment and parts abound in the oil and gas industry. In the Zardob area of Azerbaydzhan, for example, drillers lower casing strings in two sections for fear that threaded connections will break. But this procedure requires more time and makes it hard to get a hermetic seal when the two casing strings are united (an undesirable circumstance where bed pressures are high)(58). In Western Siberia each electric deep-well pump is taken apart, inspected, and reassembled before it is used(55).

Another consequence of drilling to greater depths is increased stress on the hoists, derricks, and other parts of drilling rigs that must support and raise increasing amounts of drill pipe and casing. As depths increase, drill strings come to weigh several hundred tons and hoisting equipment must have a capacity of hundreds of horsepower to handle such loads(32).

According to a CIA estimate, the USSR had about 1,800 drilling rigs operating in 1975, only about 11 percent more than the 1,624 believed to have been operating in 1965(25). Although over 1,100 drilling rigs were produced for the oil and gas industry by the Uralmash works during the period between January 1976 and April 1979(59),there are indications that drilling capacity is not adequate for Soviet needs. The CIA concluded in mid-1977 that the Soviets had been forced to shortchange exploratory drilling in order to meet current needs for production drilling(25). And, in a 1979 article, a chief designer of drill rigs for Uralmash complained that customers would not allow the completion of tests on experimental drilling rigs because this would require that the rigs temporarily be removed from active operation(60).

From a review of Soviet technical literature it is readily apparent that the Soviet capacity to drill oil and gas wells cannot be judged solely on the basis of the size of the drilling rig park (i.e., the number of drill rigs). During the Tenth Five-Year Plan many obsolete rigs such as the Uralmash-3D, 3D-61, 5D, and 4E rigs were phased out and replaced with modern improved models (e.g., the Uralmash-3D-67, 4E-67, and 160-DG-III rigs)(61).* In 1983 the Uralmash-4000D-1 and 4000E-1 made their debuts as improved rigs for rotary drilling(62).

As in many areas of Soviet technology, changes appear to have taken place in drill rigs in an evolutionary rather than revolutionary fashion. This is perhaps why the rigs described above as modern and improved models bear designations similar to rigs introduced into series production in the early 1950s (e.g., the Uralmash 3D, 4E, 5D, and 6E). Higher horsepower motors have been introduced, improved brakes have been added, and the life of diesel engines has been increased substantially (several fold in some cases)(63).

One of the most revolutionary changes in drill rigs attempted by the Soviets—a shift from traditional block-and-tackle hoists to a hydraulic hoist system—appears to be bogged down in bureaucratic problems. The concept was put forward by a group at VNIITNeft** in the 1960s, and an experimental model was tested in 1968. But the Ministry of the Oil Industry has not shown consistent support for the idea, which requires cooperation from the Ministry of Chemical and Petroleum Machine Building and the Ministry of Heavy and Transport Machine Building to come to fruition(64). The new rigs announced in 1983 (Uralmash-4000D-1 and 4000E-1) have traditional block-and-tackle hoists(62).

Although the quantity and quality of drill rigs is increasing from year to year, drillers continue to press for more and better rigs and for a better mix of rigs. With respect to the latter point, it is interesting to note the complaint of the Ukrneft Association that it was too well supplied with rigs designed to drill more than 5,000 meters deep, but not well equipped with lighter rigs designed for depths they normally were drilling—2,500–3,500 meters(61).

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*Evidently much remains to be done in modernizing the rig park: an article published in mid-1979 indicates that most of the drilling done by the Grozneft Association was being carried out with rigs having limited load capacities (primarily Uralmash-3D and 4E rigs), although 87 percent of the Association's new wells have a designed depth of over 4,500 meters (i.e., are "superdeep")(47).

**This acronym has been variously rendered as the All-Union Scientific Research Institute—for the Development and Operation of Oil Field Pipelines(64); for Transportation, Storage and Use of Petroleum Products; and of Petroleum-Processing Technology(65).

Key Organizations and Personalities

The Soviet Union has a number of organizations working on the drilling problems discussed above. The most important of these is the All-Union Scientific Research Institute of Drilling Equipment (VNIIBT). VNIIBT, which is headquartered in Moscow, is subordinate to the Ministry of the Oil Industry (Minnefteprom), but appears to also provide technology utilized in the Ministry of the Gas Industry.

VNIIBT is reported to have "scientific and design subunits that are working on the development of practically the entire range of equipment used in the process of drilling a well and preparing it to produce oil"(66). The institute has played a fundamental role in the development and refinement of the turbodrill and presently has on its staff well-known experts such as R. A. Ioannesyan and M. T. Gusman(67). Eighty percent of the drilling bits produced in the USSR were developed by VNIIBT(66). The institute is involved in research on drilling muds, inclined-directional drilling, and deep drilling; the development of core-sampling tools, drilling pipe, and improved equipment for cementation of wells; and the problems of optimization of well-drilling processes through the use of mathematical models. VNIIBT has a branch at Perm, an experimental plant,* and ten test sections located in the principal oil-producing regions(67).

In carrying out its R&D activities, VNIIBT interacts with a number of other organizations. In the design, development, and testing of drill bits, it cooperates with the Ministry of Chemical and Petroleum Machine Building (Minkhimmash); over a ten-year period the two organizations cooperated in the development of more than 130 standard bits(67). VNIIBT also has collaborated with SEVKAVNIPINeft (North Caucasus Scientific Research and Planning Institute for Petroleum) on the testing of new bits of the AN series(43).

The research of VNIIBT on drilling muds has brought it into joint development ventures with several other organizations, including the Institute of Organic Chemistry of the USSR Academy of Sciences; the Central Scientific Research and Planning Institute of the Wood-

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*This is probably the Lyubertsy plant, which reportedly is working on equipment for drilling to depths of ten to fifteen kilometers, among other things(68). However, another source has referred to a VNIIBT plant at Kotovo in Volgograd Oblast where rubber packers were being produced(69).

Chemistry Industry (TSNILKhI); VNIIKrakhmaloproduktov (evidently the All-Union Scientific Research Institute of Starch Products); and Volgograd NIPINeft (the Volgograd Scientific Research, Planning, and Design Institute for Petroleum); plus industrial testing relationships with oil- and gas-producing associations such as Nizhnevolzhskneft and Saratovneftegaz(67). VNIIBT also has cooperated with the Scientific Research Institute of the Rubber Industry (NIIRP) in the development of rubber packers(69).

A number of organizations are involved in the design, testing, and fabrication of drilling rigs. Beginning at the ministerial level, the principal users of drilling rigs are organizations subordinate to the Ministry of the Oil Industry, the Ministry of the Gas Industry, and the Ministry of Geology. Principal responsibility for the design, testing, and manufacture of drilling rigs rests with the Ministry of Heavy and Transport Machine Building and the Ministry of Chemical and Petroleum Machine Building, although supplemental equipment for rigs is supplied by organizations subordinate to the Ministry of the Electrical Equipment Industry and the Ministry of Instrument Making, Automation Equipment, and Control Systems(60, 64).

The most important organizations involved in research and design activities related to drilling rigs appear to be the Scientific Research Design Technological Institute of Heavy Machine Building (NIITyazhmash), the All-Union Scientific Research and Project-Design Institute of Petroleum Machine Building (VNIINeftemash), and the State Scientific Research and Planning Institute of Petroleum Machine Building (Giproneftemash)(63, 64, 70). NIITyazhmash, which is located in Sverdlovsk, is part of the "Uralmash" Production Association, while VNIINeftemash and Giproneftemash are both located in Moscow and are both subordinate to the Ministry of Chemical and Petroleum Machine Building(64, 71).* Other institutes that have played a role in the development of new drilling rigs include VNIIBT (discussed earlier); the Ministry of Geology's All-Union Scientific Research Institute of Methods and Techniques of Exploration (VITR); the All-Union Scientific Research and Project-Design Institute for Automatic Electric Drives in Industry, Agriculture, and Transportation

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*A CIA directory lists Giproneftemash as subordinate to the Ministry of the Petroleum Industry(72).

(VNIIElektroprivod); and the All-Union Scientific Research and Project-Design Institute of Complex Automation in the Oil and Gas Industry (VNIIKANeftegaz)(63).

The foremost center for manufacture of drilling rigs appears to be the "Uralmash" Plant* in Sverdlovsk, which is the head enterprise of the "Uralmash" Production Association and the largest heavy machine building works in the USSR. Uralmash has produced a cumulative total of more than 10,000 drilling installations(73)—including more than 1,100 during the first three and one-half years of the Tenth Five-Year Plan(59). Approximately 70 percent of all drilling rigs in operation in the Soviet Union were produced by Uralmash, and about 40 percent of annual drilling below 2,500 meters involves Uralmash equipment(63). In 1978 it was announced that plans had been drawn up for an expansion of the Uralmash works that would permit a doubling of output of a group of products, including "drilling machines for oil workers"(74). A second important center of drill rig manufacture appears to be the "Barrikady" Plant in Volgograd(63). Other plants that have had a direct or indirect role in the manufacture of drill rigs include the Plant imeni Leytenant Shmidt in Baku(63), the Yuzhgidromash Plant in Berdyansk(64), and the Machine Building Plant imeni Petrov in Baku(75).

Enhanced Recovery of Petroleum**

Description of Programs

Introduction. When an oil field is first developed there is typically enough natural pressure in the reservoir to force oil out of pores in the rock and into the well. At the end of this *primary recovery* phase, when this natural drive is exhausted, as much as 80 percent of the oil often is still in place. Additional oil can be recovered by *secondary recovery* techniques that involve repressuring the reservoir through the injection of water (waterflooding) or gas into the reservoir. More advanced approaches to enhanced recovery—*tertiary recovery* techniques—involve the treatment of reservoir rock strata with chemicals or heat. It is now considered to be technically possible to recover 70 to 80 percent of the oil in a deposit if secondary and tertiary methods are employed properly.

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*This is known more formally as the Ural Heavy Machine Building Plant imeni Sergo Ordzhonikidze(57).

**In preparing this section, the authors have benefited from the experiences of previous Battelle researchers who have investigated Soviet enhanced recovery technologies(76).

Waterflooding. The Soviet Union first began waterflooding in 1946 and now includes the technique as a routine practice in the development of petroleum reservoirs. In 1974, 220 fields (about 80 percent of all Soviet oil fields) were undergoing waterflooding, and annual injections reached approximately 800 million cubic meters of water(77). By 1980, injections of water totaled more than 1 billion cubic meters per year(78). About 90 percent of the petroleum produced in the USSR is extracted with the aid of waterflooding (1983) versus about 50 percent in the United States (1976)(79, 80). Some Soviet writers have claimed that the use of waterflooding in mature producing areas of the USSR leads to ultimate recovery rates of 50 to 60 percent* (versus 20 to 30 percent without maintenance techniques).

Because of state ownership of petroleum deposits, the Soviets have been able to develop oil fields as single units, thereby avoiding suboptimal practices that have characterized many fields in capitalist countries where ownership of a single field often was divided among a number of private parties. The Soviets have capitalized on this ease of field utilization by making waterflooding an integral part of the planning of reservoir exploitation and by introducing it early in the development of fields.

Soviet practice has called for the application of large-scale waterflooding with high pressure to reduce the number of producing wells per unit of land. As a result, the amount of land surface per well—about 120 to 160 acres—is substantially higher than in the United States. This practice allows the Soviet Union to conserve capital and to reduce the amount of drilling per ton of oil produced. It also is claimed that the application of waterflooding (and other secondary recovery techniques) increases labor productivity(81).

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*Western observers find these recovery rates very high and have suggested that the Soviets may be using a base other than total estimated oil in place. A mid-1980 remark by V. I. Kremnev (first deputy minister of the USSR Ministry of the Oil Industry) indicates that existing methods result in the extraction of a little more than 40 percent of the oil in place(78). A 1983 survey by the Oil and Gas Department of the GKNT claims a Soviet recovery rate of 43 percent (vs. 33 percent in the United States)(80).

It is clear, however, that problems arise if waterflooding is not carried out properly. When injection pressures are too high, fractures can be formed in the reservoir, thereby creating nonuniform flow patterns in which the injected water bypasses portions of the reservoir, leaving oil trapped in pockets or thoroughly mixed with water.

As an example of what can happen, one can cite the case of the Zybza deposit in Krasnodarskiy Kray where production began in 1947. Although water was not injected into this deposit during the early years of its development, natural water intrusion occurred and the water content of the fluid brought to the surface gradually increased, rising to 9 percent during 1950–51. In 1952 deliberate waterflooding began with the utilization of eight injection wells located around the periphery of the deposit. By the end of 1957 the water content had increased to 76 percent of well output and, by the latter part of 1965, to 86–88 percent(82). (Water injection was halted at the end of 1960).

Soviet technical literature indicates that problems associated with waterflooding have increased in the past decade. A November 1975 discussion of the Orenburg area reported that the water content of oil had increased from 22 percent to 26 percent in the previous two years(83). A 1975 report on the Ukrainian segment of the industry indicates that the water content rose from 20 percent in 1968 to 52 percent in 1973, increasing production costs per metric ton of crude by 0.75 rubles. Individual Ukrainian fields experienced even more dramatic increases during the six years before 1975, with the percentages of water rising from 14 to 61 in the Gnedintsevskoye field, from 34 to 68 percent at Glinsko-Rozbyshevskoye, and from 23 to 78 percent in the Kachanovskoye field(84). In early 1983 it was reported that the "water cut" (content) at the Ust-Balyk field in Tyumen Oblast (Western Siberia) had reached 81 percent(85). For the USSR as a whole, it is reported that in 1977 more than 50 percent of the fluid raised from all producing wells was water(86).

Western analysts of Soviet waterflooding practice have expressed concern that enthusiasm for heavy injection rates may have led the Soviets to ignore the special conditions of individual reservoirs that call for more moderate injection rates and pressures. In support of this concern, one can cite the experience of NGDU* Shirvanneft in

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*NGDU is the abbreviation for *neftegazodobyvayushcheye upravleniye*, or oil and gas extraction administration.

Azerbaydzhan where waterflooding of the Kyurovdag field began in the late 1950s. Water from the Kura River was used for this purpose, and it was purified before being injected. However, it was not heated and the effect of injecting cold water into the strata was to raise the viscosity of the oil and make it less mobile(87).

The Western concern about indiscriminant waterflooding also seems to be supported by complaints of V. Shashin, the late minister of the oil industry, that the use of "volumes of water injected" as a performance criterion was leading to the neglect of more fundamental considerations (e.g., pressure maintenance, production rates, recovery rates) and, consequently, to wasteful and even destructive practices(88). It also should be noted that the injected water that becomes mixed with the oil must be removed, creating a need for additional separation equipment in the fields.

Gas Injection. As an alternative to waterflooding, natural gas or some other gas can be injected into a petroleum reservoir to maintain pressure. Limited use is made of gas injection in the West because of the low inherent effectiveness of gas in displacing oil and because of the profitable market for natural gas. However, gas injection often is found to be cost-effective in situations where gravity drainage of oil is possible or where the gas cannot be sold profitably(79).

Gas injection has not yet become an important form of secondary recovery in the USSR, but there are signs of increased emphasis on this form of enhanced recovery in the past decade. In mid-1976 it was reported that flowcharts had been developed in support of plans to pump gas into the Samotlor and Vakh reservoirs of Western Siberia. It was planned that casing head gas, which previously had been flared, would be the injectant(89). A goal for 1982 was to inject 190 million m^3 of gas into the Samotlor deposit, but this goal was not achieved due to delays in the installation of compressor stations(80).

It was reported in 1979 that SevkavNIPINeft had thoroughly investigated a method for displacing petroleum with high-pressure gas that had been applied in Stavropolskiy Kray. The method, which involves injection of gas at pressures of up to 290 kgf/cm^2, is being applied in deposits being worked by the Grozneft Association(90).

In addition to using gas to repressure a reservoir, it can be injected directly into the oil to create a mixture of oil and gas that has lower viscosity than the oil alone and, hence, is easier to raise to the surface. This method of secondary recovery, referred to as "gaslift," has been employed in the USSR for ten to fifteen years but has not yet become an important method of secondary recovery(91). In the Pravdinsk deposit in Western Siberia, for example, industrial testing of Canadian gaslift equipment began in 1971, and 222 wells had been converted to gaslift by 1978, but in the latter year gaslift accounted for only 4 percent of production in Tyumen(9).

Gaslift offers advantages over other methods in raising oil that is heavy or has a high salt content. As a result, gaslift is expected to be applied especially on the eastern Caspian coast and in Western Siberia(9). The method also is being employed in Azerbaydzhan (e.g., in the NGDU imeni N. Narimanov)(92).

The Soviet gaslift effort seems to have been based heavily on imported equipment (e.g., Canadian and French), but domestic firms such as the Kazan Compressor Plant now have begun to produce air pumps and other types of equipment(9). In addition, Soviet organizations are conducting research to determine the best operating conditions for gaslift systems. As an example, researchers for Surgutneftegaz and the Ufa Petroleum Institute have studied the effect of rising water content on the efficiency of gaslift, finding that the emulsions formed often have higher viscosity, which reduces the efficiency of the gaslift(93).

Chemical Tertiary Methods. A natural step in progressing from secondary to tertiary recovery methods is to add surfactants to a waterflood. These agents reduce the interfacial tension between the floodwater and the oil, thereby reducing capillary forces that interfere with the displacement of oil from the reservoir pore spaces. The Soviets have experimented with a number of surfactants (PAV in Soviet parlance) over the past decade, including sulfuric acid, sulfanol, caustic soda, and organic surfactants. By late 1983 PAVs were being added to the waterfloods in Bashkiria, Azerbaydzhan, Tataria, the Ukraine, and Western Siberia(94). In early 1983 experiments were under way at the Mamontovo field (Western Siberia's third largest) with various surfactants, including neutralized acid asphalt(85). Results have been favorable from a technical point of view in many cases; in Azerbaydzhan's NGDU Shirvanneft, for example, a total of 163,000 m.t. of additional oil had been extracted by 1983 as a result of using PAV. However, the high cost of surfactants has kept the economics of surfactant flooding from being highly attractive. B. Gadzhiyev of Azneft notes, for example, that a ton of sulfanol costs 650 rubles and that other surfactants are equally expensive(95).

Experiments are under way to test the use of aqueous solutions of polymers such as polyacrylamide to dissolve extremely viscous oils such as those found at Karazhanbas in northwestern Kazakhstan(96). Boris Rachkov, a Soviet economist, reports that semicommercial tests of polymer floods in Bashkiria and Kuybyshev Oblast have shown that it is possible to recover hundreds of extra tons of oil for each ton of polymer (100 percent concentration) injected(97).

In the late 1970s the Soviets made a decision to support surfactant-aided recovery methods by building a large facility to manufacture surface active agents at Nizhnekamsk in the Tatar ASSR(98). Much of the technology for this plant was to come from abroad. In 1977 Pressindustria SpA of Italy received a contract to open a 250,000 ton/year ethoxylate plant at Nizhnekamsk by 1980. Salzgitter Industriebau GmbH of West Germany received a contract to build a 200,000 t/yr ethylene oxide plant using process technology supplied by Scientific Design Company of New York. Initial operation was scheduled for 1981. And in early 1979 Fried. Uhde GmbH of West Germany was commissioned to build a 100,000 t/yr alkyl phenol plant using a process belonging to Chemische Werke Hüls. This plant too was to open in 1981(98).

The Soviet Union also has experimented with carbon dioxide miscible floods since 1966. In furtherance of efforts at this form of enhanced recovery, two carbon dioxide liquefaction plants were ordered from a West German firm (Borsig) in 1978. One was to be built near Kemerovo in Kemerovo Oblast and was to have a capacity of 400,000 tons per year, while the second was to produce 1 million tons per year(9). The two plants, which are valued at $38 million, were to be completed by 1980(97).

Thermal Tertiary Methods. The Soviet Union has a number of deposits of petroleum that are highly viscous and hence difficult to exploit with normal techniques. As an example, much of the oil in the Mangyshlak and Buzachi areas on the eastern side of the Caspian Sea contains such high percentages of paraffin, asphalt, and tar that it hardens at temperatures of 20–32°C(99, 100). In one such field—the Karazhanbas field on the Buzachi Peninsula—it is estimated that only 10–15 percent of the oil can be extracted with normal methods(99). On the west side of the Caspian, in Azerbaydzhan, there are dozens of sites with large reserves of heavy viscous crude oil(101). Thermal methods for recovering such high-viscosity petroleums were proposed by Soviet oil experts in the 1930s, but they were not implemented until the 1960s(102).

Three forms of thermal stimulation are distinguished by Soviet specialists: (1) heating of the cutting-face zones of producing wells with steam, heaters, or heat from chemical reactions; (2) constant or cyclical injection of heat carriers (e.g., hot water, steam, or hot gases) into the reservoir itself; and, (3) *in situ* combustion(102).

In 1967 injection of hot water was begun at the Mishovdag deposit in Azerbaydzhan, and by 1978 the practice was being applied to all fields being worked by the parent NGDU (Shirvanneft). (As noted above, before 1967 NGDU Shirvanneft had been engaging in the counterproductive exercise of injecting *cold* water into some of its fields[87]). And, as noted in the geothermal section of this book (chapter 7), naturally occurring thermal waters have been injected into oil reservoirs in Western Siberia, Mangyshlak, and Kazakhstan to maintain pressure and lower the viscosity of heavy oils.

Steam injection has been in use since the mid-1960s and, by 1978, had been applied to more than two hundred wells, yielding over 100,000 tons of additional oil. Yields of wells have been increased from 0.1–0.5 tons per day before steam treatment to five to fifteen tons per day after. The cost of oil recovered from such wells is estimated to be two to three times lower than the industry average(102). Garushev, the head of NPO "Soyuztermneft," seems to be pleased with the results of Soviet experience with these techniques, but Gadzhiyev of Azneft is more cautious, indicating that Azneft's eight years of experiments failed to achieve planned increases in recovery rates(95, 102). On the other hand, Gadzhiyev considers the efforts on Sakhalin, where recovery rates were tripled, to be highly successful from an economic point of view(95).

Gadzhiyev is much more enthusiastic about Soviet progress in developing a "wet *in situ* combustion process." With this method, air is forced into the reservoir through injection holes and the deposit is simultaneously ignited with gas jets or electrical heaters. Superheated air is produced, which lowers the viscosity of the oil and drives it toward the production wells. When the temperature in the deposit has increased to an appropriate level, water and additional air are injected, creating steam and further stimulating the deposit. Gadzhiyev notes certain advantages of this process over traditional steam injection methods: since the steam is generated underground rather than at the surface, water of any quality, including brine, can be used and there is no need for certain surface installations such as water softeners, heating lines, special steam generators, and complicated wellhead equipment(95). Gadzhiyev also argues that the primary raw materials are air and water, but fails to note that valuable petroleum is combusted underground and should be included in cost estimates.

Organizations and Personalities

The Tenth Five-Year Plan (1976–80) saw an increased interest in enhanced recovery of oil, as reflected in one of the main directions covering the period: "Improve the use of natural resources in oil and raise the oil yield of strata." (See appendix A, item 1.b) With increased activity involving new forms of secondary and tertiary recovery, it has been necessary to bring to the effort a number of organizations outside Minnefteprom and to coordinate their activities. The result was a comprehensive program instituted in 1976 and involving the GKNT, Gosplan USSR, the Academy of Sciences of the USSR, the Ministry of the Oil Industry, and several other ministries(103).

The GKNT is responsible for the coordination of all work on the creation of new forms of equipment, technical facilities, chemical products, and reagents, while institutes of the USSR Academy of Sciences and its republic counterparts are charged with working out new processes for increasing the recovery rate(103). As an example of Academy activity, one can cite the Azerbaydzhan Academy of Sciences' Institute of Problems of Deep Oil and Gas Deposits, which has been investigating alkaline waterflooding(87).

Minnefteprom, of course, is to be the primary customer for these new techniques. Concrete plans for the introduction of new recovery technology were to be drawn up covering the oil producing enterprises of Bashkiria; the Komi ASSR; Sakhalin; Mangyshlak; the Aktyubinsk, Lvov, and Kuybyshev oblasts; Western Siberia; Tatariya; and Checheno-Ingushetiya(103). Field tests have been conducted in a number of these regions and have involved regional scientific research and project institutes such as AzNIPINeft (Azerbaydzhan Scientific Research and Project Institute for Petroleum), BashNIPINeft (Bashkir NIPINeft), and TatNIPINeft (Tatar NIPINeft).

By early 1983 more than one hundred scientific research, design, and production organizations under fourteen ministries and departments were supporting enhanced recovery efforts(80). The Ministry of the Petrochemical Industry and the Ministry of the Chemical Industry were given responsibilities for introducing capacity for large-scale production of the necessary chemical reagents by the end of the Tenth Five-Year Plan (1980). Enterprises and institutes of the machine-building ministries are to develop, produce, and supply to oil workers high-pressure steam generators, compressors for injecting gas and air into deposits, and other special forms of equipment(103). The Ministry of Chemical and Petroleum Machine Building, for example, is to supply equipment for the injection of steam at temperatures of up to 345°C and pressures of 160 atmospheres(80). The Ministry of the Electrical Equipment Industry is to organize series production of new devices and means of automation. Finally, the USSR Ministry of Higher and Specialized Secondary Education is to assist by training cadres of specialists who understand and can apply the new techniques(103).

As part of its response to this comprehensive plan, Minnefteprom has sought to better focus its efforts to develop and implement new tertiary recovery techniques by establishing a Main Administration for Raising the Petroleum Yield of Deposits and by creating two specialized science-production associations—NPO "Soyuzneftepromkhim" and NPO "Soyuztermneft"(78).

Soyuztermneft came into existence on January 1, 1978, and ultimately is to include Krasnodar NIPINeft, NGDU "Chernomorneft," all thermal recovery demonstration sections, and an experimental-industrial base for building special machinery(102). Soyuztermneft is to prepare plans for the development of oil fields in which thermal methods are appropriate, design suitable equipment and machinery, supervise the equipping of oil fields, and generally promote the adoption of techniques developed by the NPO. As an example, Soyuztermneft has accepted responsibility for the development of design documentation for thermal recovery work to be undertaken in the Umbaka deposit and the Balakhani-Sabunchi-Romani deposits in Azerbaydzhan(101).

As a final point on thermal recovery, a 1979 editorial in *Vyshka* (Baku) urged that AzNIPINeft and AzNIIEnergetika (Azerbaydzhan Scientific Research Institute for Power Engineering imeni I. G.

Yesman) should play a more prominent role in the development of thermal recovery methods(101).

One of the most important advocates of enhanced recovery in the USSR is Arkadiy M. Lalayants, a deputy chairman of Gosplan. Lalayants has argued that it could be possible for the USSR to raise the average recovery rate by 10 to 12 percentage points using known methods of enhanced recovery(103). Other proponents include Aleksandr R. Garushev, the head of NPO Soyuztermneft (102), and B. Gadzhiyev, the general director of Azneft (the State Association of the Azerbaydzhan Oil Industry)(95).

Evaluation

It is not surprising that the Soviet Union is devoting increased attention to enhanced recovery of crude oil from existing deposits, given the remoteness of new petroleum sites from consumption centers. Tremendous amounts of oil remain in the ground in older oil-producing regions that are already well supplied with supporting capital infrastructure for the transportation, storage, and processing of petroleum and for the housing of oil workers. By contrast, new deposits are in hostile regions (e.g., Siberia) that lack roads, electricity, housing, and all of the capital equipment needed to handle oil.

In spite of numerous Soviet articles on enhanced recovery techniques in scientific publications, and assertions that Soviet experts were the first to put forth many of the ideas current in the field(82), the USSR did not make significant progress in applying enhanced recovery techniques (other than waterflooding) for a number of years. As an example, during the period 1967–76 only about 6 million tons of additional oil were produced as a result of thermal treatments of wells and beds—a little over 0.1 percent of the total oil and gas condensate produced during that period(82). A 1975 assessment of Soviet technology for enhanced recovery rated their waterflooding technology as approximately comparable to that of the United States, but found their experience with tertiary techniques to be quite limited(76).

The comprehensive program instituted in 1976 was a turning point for the Soviet Union in this field. At that time the USSR made a decision to move into enhanced recovery in a meaningful way and to acquire or develop the necessary technology, equipment, and chemical production capacity needed to support greatly expanded tertiary recovery efforts.

The subsequent Tenth Five-Year Plan was largely a period of experimentation with enhanced recovery techniques rather than a period of commercial application of such methods. By mid-1980 it was reported that experiments with a number of techniques had been carried out at forty-five locations throughout the country and that it was possible, on the basis of these results, to forecast an increase in recovery rates by 10 to 15 percentage points, and thus to reclassify several billion tons of oil as active reserves(78).

During the Eleventh Five-Year Plan, enhanced recovery methods began to be applied on a commercial rather than experimental basis. As of February 1983 the new methods were being applied at fifty-six locations in twenty-two production associations(80).

Implementation of the 1976 comprehensive program has not proceeded smoothly and has been marked by tensions and finger pointing. In March of 1979 an editorial in the Baku daily *Vyshka* noted that thermal methods had been introduced in four Azerbaydzhan NGDUS but that good results had been obtained in only one of these—the NGDU of Leninneft (in Leninskiy Rayon). Problems noted included inadequate compressor capacity, difficulties in starting up modern equipment required for *in situ* combustion process, and delays in setting up high-capacity steam generators(101). In September 1979 *Pravda* printed complaints that institutes developing plans for the exploitation of oil fields requiring thermal methods were not paying enough attention to the chemistry of the oil reservoirs or of the water to be injected, and that there were chronic shortages of equipment, including underground pumps capable of operating at the high temperatures encountered in handling natural thermal waters, control and measuring apparatus needed for the wet *in situ* combustion process, and desalination units needed for the steam treatment of reservoirs(99).

In February 1983 an article in *Ekonomicheskaya gazeta* written by personnel of the GKNT pointed out a number of problems. The "Nizhnevartovskneftegaz" Association was criticized for failing to introduce compressor stations for the high-pressure injection of hydrocarbon gases at the Samotlor field, and blame was shared by two firms that had failed to supply equipment needed for the project

—the Machine Building Plant imeni Leytenant Shmidt (Baku) and the Ust-Kamenogorsk Fittings Plant (in eastern Kazakhstan). The Ministry of Chemical and Petroleum Machine Building was criticized for not producing needed pumps for the injection of carbon dioxide and wellhead equipment for the injection of steam(80).

Similar complaints were voiced in mid-1983 in Azerbaydzhan where attempts to test caustic soda waterflooding in the Kyurovdag deposit have been hampered by a lack of dosimeter pumps and a shortage of chemical agents: used pumps of the wrong type were supplied, and only thirty-three tons of alkaline were made available instead of the nine hundred tons requested. An official of the parent unit (NGDU Shirvanneft) also complained that modern waterflooding operations there were being held back by shortages of high-pressure valves, flowmeters, electric motors, and proper types of pumps, and by slow movement of new devices from design bureaus to field operations(87).

In spite of these problems the Soviets have clearly made progress in applying tertiary recovery techniques, almost doubling the production of oil attributed to these methods from 1975 to 1980, and registering further increases since 1980. Reported and implied production figures due to these techniques are as follows: 1975, 1.4 million m.t. (reported); 1980, 2.7 million m.t. (reported); 1982, 3.5 million m.t. (implied).*

Production due to tertiary recovery methods was less than 0.6 percent of total oil production in 1982,** however, and we see little prospect that the Soviets will reach their 1985 goal of 8 million m.t., or even raise tertiary recovery to 1 percent of total production by 1985(80). By contrast, it was estimated in the fall of 1984 that about 6 percent of U.S. production was due to enhanced recovery techniques. (However, the percentage rate of increase since the mid-1970s appears to have been higher in the USSR[104].)

It is evident that success in meeting the 1985 goal will be heavily dependent on progress on the Buzachi Peninsula where production is to rise from 3.7 million m.t. in 1983 (planned) to 5 million m.t. in 1985(100).

In the long run, there would seem to be no serious technical barrier to a substantial expansion of the role of tertiary recovery methods in the Soviet oil industry if these efforts are given adequate financial support. Economic considerations, of course, will influence which methods and geographic sites are developed first. However, given the variety of conditions encountered in different regions and fields, and even in strata within a single field, we wonder whether the crude and often perverse incentives engendered by the Soviet planning system will not lead to blind and even destructive production methods once tertiary methods pass from the hands of researchers and become standard practices. Soviet experiences with water injection techniques provide ample reason for concern, particularly when one finds indications of a plan to pump 300 million m^3 of gas into a formation during the Tenth Five-Year Plan as part of a gas injection project(90).

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*The 1982 figure is said to be 30 percent higher than that for 1980(80).

**That is, 3.5 million m.t. vs. 612.6 million m.t.(1, 80).

Offshore Technology

Introduction

The USSR borders on approximately 40 percent of the continental shelf area of the world, most of which has not yet been drilled(105). Crude oil and gas deposits are believed to be present in many of these offshore areas, but much of the prospective shelf reserve lies above the Arctic Circle and hence will be difficult, dangerous, and expensive to develop. If the Soviet Union is to make use of these reserves, it must develop or import the necessary technology or must enter into joint agreements with Western companies.

To date, Soviet efforts at offshore development have been modest and have been limited largely to exploration and production efforts in the Caspian Sea, although some offshore exploration activity has also taken place near Sakhalin Island in the Pacific(106), in the Sea of Azov, in the Black Sea, (exploration and gas production)(105, 107), and, recently, in the Barents Sea(108) and in the Baltic Sea(109).

According to Western reports, these efforts have not been sufficient to hold offshore production of crude oil and condensate steady, although natural gas production has risen. In 1983 offshore output of crude was only about 175,000 barrels per day (b/d), down from approximately 200,000 b/d in 1980 and 258,000 b/d in 1970(110, 111). Offshore gas production, on the other hand, rose from 1.16 billion cubic feet per day (cfd) in 1979 to 1.42 billion cfd in 1982(111). Doubt has been expressed that the Soviets would be able by 1985 to regain the crude/condensate output rate they achieved in 1970, but respectable gains in offshore gas production are expected in the 1980s(110).

Soviet accounts seem to support the pessimistic picture of offshore oil production: a newspaper report in October 1982 indicated that annual oil production in the Caspian Sea had fallen from almost 5 million m.t. in the recent past to under 3 million m.t. and was expected to drop to 2 million m.t. in 1985(112). This bodes ill for the overall Soviet effort because, despite discoveries in a variety of locations, it was considered likely that the Caspian Sea would still account for more than three-fourths of Soviet offshore oil and gas production in 1985(110).

Equipment Available for Offshore Work

Introduction. Domestic Soviet equipment for offshore exploration and development lags well behind that of the West. Strictly speaking, the USSR has more than fifty years of experience in raising oil from offshore fields in the Caspian Sea, but most of this has been carried out via directional drilling from on shore,* from fixed trestles that stretch from shore (e.g., Neftyanyye Kamni), or from manmade islands. In 1979 the Soviets added some thirty fixed platforms in the Caspian, bringing the total number (including free-standing platforms and ones located near fixed trestles) to roughly one thousand(110). In the Baltic Sea, however, the Soviets had only a single stationary platform as of early 1983(109). The weaknesses of Soviet offshore capabilities are most noticeable in the case of mobile rigs, where they were judged in 1980 to be behind not only many Western nations, but also the People's Republic of China(110).

Jackups. A jackup is a floating drilling rig with legs that can be extended to allow the rig to stand on the ocean floor while drilling. As of June 1984 the USSR had at its disposal only eleven jackup drilling platforms—a modest number considering the amount of continental shelf on its borders (see table 7). Two of the jackups —the "Apsheron" and the "Azerbaydzhan"—reportedly cannot operate in water more than twenty meters deep and have been described by the CIA as "obsolete"(25). The Apsheron is capable of drilling to

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*For a discussion of the use of the turbodrill in directional drilling, see earlier portions of this chapter.

Table 7 Equipment Available for Soviet Offshore Work

		Built	
Type	Name	Date	Place
Jackup	Apsheron	1966	Baku
	Khazar	1967	Rotterdam
	Azerbaydzhan	1971	Baku
	Baky	1975	Astrakhan, Baku
	60 let Oktyabrya	1977	Astrakhan[b]
	Sivash	1978	Sevastopol
	Okha	1980	Japan
	60 let Azerbaydzhana	1981	Astrakhan, Baku
	XXVI Syezd KPSS	1982	Astrakhan
	28th of April[d]	1983[d]	Astrakhan[d]
	Ekhabi[c]	1984[c]	Singapore[c]
	Unnamed	1985	Finland
	Unnamed	1985	Finland
Semisubmersible	Kaspmorneft	1979	Astrakhan, Baku
	Shelf-1	1981	Astrakhan
	Shelf-2	1982	Astrakhan
	Shelf-3[a]	1983[a]	Astrakhan[a]
	Shelf-4	1984[e]	Vyborg
	Shelf-5	1984	Vyborg
	Shelf-6	1984	Vyborg
	Shelf-7	1985	Vyborg
Drill ships	Valentin Shashin	1981	Finland
	Viktor Muravlenko	1982	Finland
	Mikhail Mirchink	1982	Finland

Sources: Reference (114), except as noted: a Reference(115), b Reference(9), c Reference(116), d Reference(208), e Reference(209).

depths of only 1,800 meters, but the Azerbaydzhan can reach 3,000 meters. Both were built in Baku and both operate in the Caspian.

The other nine jackups are considered modern. The first to see service was the Dutch-built "Khazar," which began work in the Caspian in 1968(110). The Khazar can drill to 6,000 meters in up to sixty meters of water. Five of the other eight modern jackups were built in the Soviet Union as part of an ambitious program launched in 1970 and aimed at constructing ten standardized rigs between

1973 and the end of 1980(110, 113). Four of the jackups built in this period are of the Kaspiy-class. These are the "Baky," "60 let Oktyabrya,"* "Sivash," and "60 let Azerbaydzhana."** The Baky, which was fielded in 1975, has depth capabilities similar to those of the Dutch-built Khazar (6,000/60)(113).*** In the fall of 1982 the Baky was reported to have drilled a well in the Caspian to nearly 4,000 meters and was to continue to 6,000 meters(117). Construction of the 60 let Oktyabrya began in 1974 and was completed during the summer of 1977(105, 118). This jackup has legs that can extend to a length of more than 108 meters, permitting the rig to drill in up to seventy-five meters of water(118). It has been operating in the Caspian since January 1978(110). The third rig in the series—the Sivash—has depth capabilities similar to the Baky and the Khazar (6,000/60) and was reported in January 1981 and December 1983 to be operating in the Black Sea(119, 120). The latest in the Kaspiy series of jackups is the 60 let Azerbaydzhana, which was built in Astrakhan in 1981(114). The "XXVI syezd KPSS" (26th Congress of the Communist Party), which was completed in 1982, has greater depth capabilities than the other Soviet jackups (6,150/75) and is described by the journal *Offshore* as not part of the Kaspiy class, but of the "Orion" design(114). In December 1982 it was reported to be headed for the Livanova Bank in the Caspian where it was to drill to 6,000 meters. This rig can drill three holes without moving—one vertical and two inclined(121). The "28th of April" was commissioned late in 1983(208).

It is apparent that the Soviets have not been totally satisfied with their domestic capabilities to build jackups, as evidenced by several recent orders for foreign rigs. One was for the "Okha," which was built in Japan in 1980. The Okha can drill to about 6,000 meters in about seventy meters of water(114). In November 1982 the Okha was reported to have completed a season of prospecting off the northeast coast of Sakhalin Island(122).

A second order was for the "Ekhabi," which was completed in mid-1984 by Singapore's Far East Levingston Shipbuilding. The Ekhabi, which reportedly will accommodate eighty people, will join

*Sixtieth Anniversary of October.

**Sixtieth Anniversary of Azerbaydzhan.

***An industry analyst tells us that this is not accidental and that the Kaspiy series was modeled after the Khazar.

the Okha for work in the Sea of Okhotsk off Sakhalin(116). And in early 1983 it was announced that the Soviets had ordered two jackups from Finland's Rauma-Repola for work in the Arctic. The rigs, which are said to be the largest in the world, were to be delivered in June and November 1985(123).

Semisubmersibles. The USSR has been working on the development of semisubmersibles since at least 1975 and, by the end of 1983, hoped to have five in the field(105) (see table 7).

"Kaspmorneft," the USSR's first semisubmersible rig, might well be termed an international conglomeration. The rig was ordered from Armco International, Inc., of the United States, which supplied much of the equipment for the rig(124), but relied on Friede and Goldman for the design(123). The hull for the rig was built by Rauma-Repola Oy of Finland and towed in sections from the Baltic to Astrakhan (on the Caspian) via the Soviet internal waterway system(124, 125). Assembly of the rig was carried out by the Marine Shipbuilding Plant in Astrakhan and completed during the summer of 1979(126). In January 1981, Kaspmorneft was reported to be undergoing sea trials in the Caspian(119), and in May 1983 it was said to be operating in the "28th of April" Field (off the Apsheron Peninsula)(115).

The second Soviet semisubmersible, "Shelf-1," is to be able to drill to 6,000 meters in up to two hundred meters of water (127, 128). Shelf-1 was developed by Soviet designers, with twenty scientific research and planning institutes participating in its creation(129). Drilling equipment was supplied by the "Uralmash" Plant in Sverdlovsk, and final assembly took place at the Marine Shipbuilding Plant in Astrakhan (late 1980)(128, 129, 130). Following trials at the Oil Field imeni Faud Samedov in the Caspian Sea, the new semisubmersible was sent to the 28th of April Field for final testing and initial production work (February 1982). The first well drilled there was to be 4,500 meters deep(129). In May 1983 it was reported to still be in the 28th of April Field(115).

A third semisubmersible, "Shelf-2," left Astrakhan and arrived in Baku in the fall of 1982(131). Shelf-2, like its predecessor, is designed to drill to 6,000 meters in ninety to two hundred meters of water. It carries a crew of eighty and can store enough supplies to function for thirty days. While drilling, it is held in place by up to eight anchors weighing 18 m.t. each and attached to the rig by chains. Power is provided by five diesel generators, each having a capacity of 1,000 kw.* Drilling operations are to be monitored by underwater television(132). In May 1983 Shelf-2 was reported to be drilling its first well in the Kaverochkin structure (Caspian Sea)(115). Figure 5 shows a photograph taken at about that time, with Shelf-2 reported to be drilling a 4,500-meter well in 165 meters of water.

A fourth semisubmersible, "Shelf-3," was reported in May 1983 to be under construction in Astrakhan, with launch planned for the spring or summer of that year(115). Shelf-3 will be able to drill to 7,000 meters—1,000 meters deeper than Shelf-1 or Shelf-2(133).

Beyond these four semisubmersibles—all of which are deployed or intended to operate in the Caspian Sea—the Soviets have been working on additional ones to operate in other seas. Late in 1982 it was announced that the shipyard at Vyborg (on the Baltic above Leningrad) had launched the hull for a semisubmersible that will be able to drill to 6,000 meters in 200 meters of water(134). The journal *Offshore* has identified this as "Shelf-4" and foresees a total of four semisubmersibles being produced at Vyborg by 1985 (see table 7).

Finally, there remains the mystery of the Sevastopol semisubmersible. In 1978 a Soviet newspaper reported that construction was under way in Sevastopol on a mobile drilling rig having over 6,700 m^2 of area, a 6,000-kw electric power plant, and capability of drilling to 6,000 meters in up to 200 meters of water(135). Although not stated explicitly, the water depth capability and an accompanying drawing indicate that the rig was a semisubmersible. In 1980 David Wilson referred to a semisubmersible under construction in Sevastopol(9). In January 1981 the Western publication *Offshore* listed an unnamed semisubmersible that was to be delivered to Sevastopol in 1981(119). However, Soviet radio broadcasts made in October 1982 and a professional journal released in December 1982 indicated that all Soviet semisubmersibles built to date had been produced at Astrakhan or Vyborg and that none were operating outside the Caspian Sea(132, 134). Perhaps there never was such a rig, and erroneous reports began when the "Sivash," a jackup built in Sevastopol in 1978, was incorrectly described. Or perhaps there is a more interesting story waiting to be told.

Drill Ships. The current stage in Soviet offshore development is being marked by the acquisition of drill ships. In the spring of 1979

*Another source says that three of the generators on Shelf-2 have a total capacity of 20,000 kw, but we doubt the accuracy of this newspaper account(131).

the Soviet import combine "Sudoimport" let a contract for $230 million to Rauma-Repola Oy of Finland to supply three dynamically positioned drillships for use in the Barents Sea(136). The three ships —the Valentin Shashin, Viktor Muravlenko, and the Mikhail Mirchink —are based on designs which Rauma-Repola has licensed from RSV-Gusto Engineering of Holland(123, 136). The Valentin Shashin was delivered to the Soviets in December 1981, the Viktor Muravlenko in June 1982, and the Mikhail Mirchink in September 1982(123).

Assuming that the three diesel-electric drill ships are basically similar in design, the typical drill ship is 150 meters in length, has a derrick that is almost 25 meters tall, and can drill to a depth of 6,500 meters in up to 300 meters of water (137, 138). The ship is kept in a stationary position by five 1.38-kw thrusters operating in conjunction with a satellite navigation system and acoustical beacons located on the ocean floor(136). These thrusters, which are located in the bow and stern sections of the ship, are controlled by three computers that process information on the force of the wind, waves, currents, and other factors fed to them from sensors(137).

Two of the drill ships—the Valentin Shashin and the Viktor Muravlenko—were indeed sent to the Barents Sea where they have been engaged in geological exploration work(137). However, the third vessel—the Mikhail Mirchink—was not sent to the Barents Sea but to the west coast of Sakhalin Island in the Pacific Ocean(138).

According to Norwegian press stories appearing in October 1982, the first attempts of the Soviets to drill on the continental shelf of the Barents Sea were a failure. These reports indicated that the automatic positioning system of the drill ship (not identified by name) failed, causing the ship to drift. In the process, the drill bit, which was in use, broke off and great damage reportedly was done to the drilling equipment and fasteners on the ship. As a result, drilling activity was halted, at least temporarily(108). By the following spring the Soviets had regained enough confidence in their abilities to allow a visit on the Valentin Shashin by a *Pravda* correspondent(137). In 1984 the Valentin Shashin was reported to have drilled a well in the Barents Sea in about 190 meters of water. (It is indicative that sixty wells were drilled in deeper waters around the world in the same year, with eighteen being drilled in waters more than twice as deep[139]).

Production, Design, and Research Facilities

The USSR has gained substantial experience in the fabrication, erection, and operation of stationary platforms, having installed more than a thousand of them over the years(110). One center for the manufacture of such fixed platforms is the October Revolution Machine Building Plant in Baku(140).

A number of facilities involved in the production of mobile offshore drilling rigs have been identified in the open literature. According to *Offshore,* the first two jackups built in the Soviet Union—the Apsheron (1966) and the Azerbaydzhan (1971)—were constructed at the Paris Commune Shipyard in Baku(114). More important in recent years has been the Shipbuilding Production Association imeni 60-letiya SSSR* (SPO), located in Astrakhan at the confluence of the Volga River and the Caspian(133). SPO was formed in the mid-1970s through the amalgamation of three enterprises—the Marine Shipbuilding Plant (the chief enterprise of SPO), the "Krasnyye barrikady" Plant, and the Plant imeni Marks [i.e., Marx]. SPO, which is led by V. Bezzhonov (the general director), apparently built the Kaspiy-series jackups and is building "Shelf" semisubmersibles(127). In order to handle its expanded manufacturing responsibilities, SPO's Marine Shipbuilding Plant has been reconstructed over the past several years(127, 141). A Western trade publication indicates that this reconstruction work has been handled by Blohm & Voss AG of West Germany(141).

In its production activities SPO interacts with a number of domestic and foreign enterprises. Drilling equipment is supplied by the "Uralmash" Machine Building Plant. Other components are supplied by the "Krasnyy molot" Plant (in Groznyy), the Plant imeni Sardarov** (in Baku), and the Khadyzhensk and Nalchik Works(142). Parts for the semisubmersible rig Kaspmorneft, which was assembled by SPO, were manufactured by Armco International (United States) and the shipyard of Finland's Rauma-Repola Oy(124, 126). In 1977 SPO received a floating shipyard built in Bulgaria to aid in the construction of offshore rigs(143).

At least three other Soviet facilities are engaged in the production of mobile drilling rigs. One is a shipyard in Sevastopol that was reported in 1978 to be working on a drilling platform capable of drilling to 6,000 meters in up to 200 meters of water(135). A second is the shipyards of the Amur Shipping Line, which were reported in 1977 to be building the prototype of a series of self-propelled trimarans for use as drilling rigs. This prototype, which was built at Nikolayevsk-na-Amure, was to be sent to geologists of the Maritime Territory(144). Finally, the Vyborg Shipyard near Leningrad was reported late in 1982 to have launched the basic structure for the first of a series of semisubmersible drilling rigs. The first rig will displace 20,000 m.t. and, like the Shelf series of semisubmersibles being built at Astrakhan, will be able to drill to a depth of 6,000 meters in up to 200 meters of water. Creation of a second center for the production of semisubmersibles will facilitate Soviet efforts to use such rigs outside of the Caspian Sea(134).

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*Sixtieth Anniversary of the USSR.

**The Plant imeni Sardarov is one of the twelve enterprises included in Soyuzneftemash(50). (See note on p. 100.)

Research and design efforts aimed at improving Soviet offshore capabilities are under way at a number of Soviet facilities. Gipromorneftegaz (the State Scientific Research and Planning Institute of Offshore Oil and Gas), which is located in Baku, designs stationary drilling platforms(122, 145). In its work Gipromorneftegaz interacts with the Institute of Electrowelding imeni Paton, the Central Scientific Research and Planning Institute of Structural Metal Assemblies (TsNIIProyektstalkonstrukstiya), and the Scientific Research Institute of Foundations and Underground Structures (NIIOSP) imeni Gersevanov(122).

A second center of offshore research and design work is the Leningrad Shipbuilding Institute (LKI), which has a laboratory devoted to the hydrodynamics of technical equipment to be used offshore. This laboratory is concerned with the behavior of floating drilling platforms and drilling vessels (e.g., in the face of current and wind) as part of LKI's pursuit of a complex of research on the problem "Technical Equipment for Studying and Opening Up the Ocean." LKI is heading this scientific effort on behalf of the USSR Ministry of Higher and Specialized Secondary Education, to which LKI is subordinate(146). The Moscow All-Union Scientific Research, Planning, and Design Institute for Total Automation in the Oil and Gas Industry has developed a system for monitoring drilling conditions at sea (SKU-"More"). The first of these systems was installed on Shelf-2(131). Other contributors to the technology of Shelf-2 include the Azerbaydzhan Scientific Research Institute of Petroleum Machine Building (developed a mooring system), the Sumgait Neftekhimavtomat Scientific Research and Design Institute ("Yakor" automatic stationkeeping system), and AZNITEI [expansion unknown] (wellhead equipment control console)(131).

Another center of R&D efforts is the Ministry of Geology's All-Union Scientific Research Institute of Marine Geology and Geophysics (VNIIMorgeo). This institute's Laboratory for Methods and Technology of Marine Geological Prospecting is developing and testing special equipment for exploration of shelf regions. Specific devices under development include a seismo-acoustic apparatus for gathering information on rock structures on the seafloor; the "KMO-7"—a device for mechanical sampling of the ocean floor; and a lightweight floating drill rig for exploratory drilling(147).

Finally, the USSR Academy of Sciences has sought to further offshore technology. As an example of its efforts, one can cite the 1978 all-union conference that it sponsored in Sevastopol on the topic "Design Principles of Floating Drilling Rigs"(148).

As a result of the activities of these and other organizations, a number of ministries or other national organizations have become involved in the Soviet effort to develop offshore oil and gas. These include the Ministry of Gas, the Ministry of the Shipbuilding Industry, the Ministry of Geology, the Ministry of Chemical and Petroleum Machine Building, the USSR Academy of Sciences, and the USSR Ministry of Higher and Specialized Secondary Education.

Evaluation

Soviet offshore oil and gas efforts clearly have lagged those of leading Western countries, but the Soviets are making gains—at least in terms of the absolute level of their activities. Jackups, semisubmersibles, and drill ships now are operating in Soviet waters, so that Soviet capabilities to drill in deeper waters are advancing.

To date, most Soviet offshore work has been carried out in the Caspian Sea. It has not been irrational for the Soviets to concentrate their limited offshore capabilities in this area, at least initially. Oil has long been produced at numerous points on both the west and east coasts of the Caspian, and it is likely that a great deal of oil remains to be discovered offshore. With an area of over 152,000 square miles (57 percent of the area of Texas), the Caspian should provide exploration and production opportunities for years to come. The fielding of modern jackups and semisubmersibles with capabilities to drill in up to two hundred meters of water has opened large areas of the Caspian to exploration. However, some 25 to 35 percent of the Caspian is more than two hundred meters deep, and these areas will be accessible only with drill ships.

As of mid-1984 there were indications of some success in the Caspian. The 28th of April Field had ten producing wells and fifteen more were expected to be added before the end of 1985. Production in this field, which could exceed 50,000 b/d in 1986, may already have stopped the decline of overall Caspian Sea production(149).

Beyond the Caspian, the Soviet Union has vast areas of continental shelf available for exploration—if only it can import or develop the technology necessary to function successfully in challenging offshore environments. The Soviets have relied heavily on foreign technology in a number of instances—the jackups Khazar, Okha, and Ekhabi, the semisubmersible Kaspmorneft, and the three Finnish drill ships. However, it also has been working hard to develop domestic capabilities for the design and fabrication of modern mobile offshore rigs. Five modern jackups have been built in the USSR in the past decade, and shipyards in Astrakhan and Vyborg now are producing semisubmersibles. Supporting these production facilities are numerous research and design organizations that are working on problems of rig fabrication and control technology.

As with other areas of Soviet energy, offshore development has been hampered by a certain amount of bureaucratic confusion. As an example, during Mitsubishi's five-year effort to supply equipment for an offshore rig production facility, the end-user for the equipment changed from one ministry to another (to the Ministry of the Shipbuilding Industry) and responsibility for offshore development was shifted from the Ministry of Oil to the Ministry of Gas(141).* Bezzhonov, the general director for SPO, complained in 1978 that no one had yet designated design organizations that were to be responsible for shipbuilding technology and for the electrical equipment needed for drilling rigs(142).

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*The USSR Ministry of Gas Industry was given responsibility for all offshore oil and gas work, effective January 1, 1979(150).

Finally, it would be surprising if Soviet offshore capabilities were not being held back by the basic weaknesses in drilling equipment manufactured in the USSR—turbodrills, drill bits, drill pipe, etc.

Nevertheless, while the USSR may continue to lag behind the West in offshore technology, there is no reason to believe that it cannot ultimately master this technology and open up large areas of continental shelf to hydrocarbon production.

Pipeline Transport of Arctic Gas

Introduction

The USSR is endowed with abundant natural gas resources. Unfortunately, the recent discoveries of gas "superfields" have been in the Arctic regions of Western Siberia. The remote location of these fields and their inaccessibility due to the area's hostile climate and difficult terrain have combined to make the exploitation of these resources costly. (One half of the USSR's sixty all-union ministries are participating in the construction of the Urengoy-Uzhgorod export gas pipeline[151]). Winters in the Western Siberian Arctic tundra last eight months, during five of which the temperature never rises above −20°F and can fall to nearly −70°F(152). Winter winds can reach speeds of ninety miles per hour, resulting in blizzards and drifting of snow. Summer temperatures rise as high as 75 to 85°F, but result in the thawing and subsidence of the permafrost making ground travel impossible over large areas. (The permafrost subsides in places by 30–40 cm per meter of thawed permafrost[152]). The Arctic also has many physical obstacles to pipeline construction. The Messoyakha-Norilsk pipeline system, for example, crosses eighty-five rivers, including the 3,000 meter wide Yenisey, fifteen major marshes, and numerous lakes along its 200-km-long route. Lines leading southwest from Urengoy also must contend with mountains.

The resources needed to overcome the technical problems connected with the laying of the pipelines themselves have been enormous and have required the development of new types of construction methods and equipment. More important, the Soviets have not had the technology to produce pipe and compressor stations of the required quality and quantity needed for full-scale exploitation of the Arctic gas fields. Their development, therefore, has made necessary both the import of Western technology and the stepping-up of indigenous R&D and production efforts in this area in order to substitute domestic for foreign technology. Western technology has alleviated Soviet supply problems connected with quality pipe steel, large-diameter steel tubemaking, compressor technology, construction equipment, communications, and a wide variety of other related technologies. (Large-diameter tubes, for example, are being supplied by West Germany, Japan, Italy, and France; such tubes constitute the bulk of the tubes being used on the Urengoy export pipeline(153)). Soviet reliance on Western technology, while necessary within the framework of planned timetables for exploitation of Arctic gas, should not be viewed as permanent. The unique problems encountered have made vigorous pipeline R&D programs necessary. In addition, U.S. attempts to prevent Soviet acquisition of certain technologies critical to the completion of the Urengoy-to-Western Europe pipeline have strengthened Soviet resolve to complete the export pipeline on schedule and to overcome domestic design and production inadequacies, as happened during a similar U.S. embargo in the early 1960s(154). As a result, the Soviets have developed their own capacity to produce 1,420-mm (56-inch) cold-resistant tube, including 1,420-mm laminated tube; have produced prototype 16- and 25-MW compressors (which they claim are the equal of any Western analog); and have successfully tested and produced automatic welding equipment for use in the Arctic. Such developments should, within a few years, allow the Soviets to pursue their Arctic pipeline program independently, albeit at a probably slower rate.

The first pipelines out of the north Tyumen Arctic region transported gas from the Medvezhye gas field, just west of Urengoy. These pipelines followed a route across the Middle Urals to central European Russia. Development of the Urengoy gas field began in 1974. Production began around 1978, and the initial gas was fed westward into the Medvezhye pipeline(155). By the end of the Tenth Five-Year Plan, a pipeline running south from Urengoy to Surgut and a second pipeline running to Medvezhye and on to central European Russia were under construction. Three additional pipelines running west from Medvezhye also had been completed(156).

Other Arctic gas pipelines included the pipelines running east from Messoyakha gas field to the mining center of Norilsk,* some

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*Norilsk is at a latitude comparable to that of Alaska's Prudhoe Bay. Urengoy is roughly at the same latitude as Fairbanks, Alaska.

500 km northeast of Urengoy, and the pipeline from Usinsk near the Arctic Circle, south to the "Northern Lights" corridor. Construction of the first Messoyakha-Norilsk pipeline began in 1968, and the line appears to have been subject to repeated breakdowns. At present three pipelines have been built to Norilsk, all apparently 720 mm in diameter. A fourth was under construction in early 1983(157).

Development of the Western Siberian oil and gas region in the Eleventh Five-Year Plan is being handled within the framework of a major national comprehensive program (see chapter 2). In addition, the USSR Gosplan has created a regional commission, based in Tyumen, to facilitate its activities related to the program. Construction of the pipelines and about three-fourths of the compressor stations is being handled by the USSR Ministry of Oil and Gas Industry Facility Construction (Minneftegazstroy), which was created in 1973 for the purpose of building the network of pipelines out of the Urengoy region. The remaining compressor stations are being built by the USSR Ministries of Power and Electrification, Construction, Industrial Construction, and Special Construction and Installation Works(158). Plans for this period call for the construction of six additional pipelines from the Urengoy area, including the controversial export pipeline, at a combined cost of 25 billion rubles, or an outlay on the order of 3 percent of the potential total volume of investment in the Eleventh Five-Year Plan(159). The new lines will run along the Medvezhye corridor southwest to Punga, where one pipeline will follow the older "Northern Lights" route, while the remaining five (including the export pipeline) will follow a more southerly route. The new pipelines will be 1,420 mm in diameter and will have a collective length of nearly 20,000 km(160). The planned pipeline program is ambitious, entailing the laying of over twice as much 1,420-mm pipeline as in the Tenth Five-Year Plan(161). (The Soviets plan to lay 63,000 km of pipeline in all between 1981 and 1985 versus 53,000 planned for the preceding five-year period[162]). Although the program is ambitious, it is likely that resource allocations will be increased, if necessary, to ensure the completion of the Urengoy pipeline projects, especially the export pipeline. The importance of these pipelines to the Soviet economy was made explicit by the late General-Secretary Brezhnev at the November 1981 Party plenum where he stated that the construction of the West Siberia-to-the-Center and export pipelines were "central projects (*stroyki*) of the five-year plan and must be completed on schedule without fail"(163). According to the Soviets, as of the end of 1983 four of the pipelines, including the export pipeline, had been completed, while the other two were near completion(159). (Welding work on the export pipeline was reported to be complete in mid-1983, but many, if not most, of the compressor stations had not been put into operation as of the end of 1983.)

The Arctic gas delivery system probably will be extended even farther north in the Twelfth Five-Year Plan (1986–90). Likely projects would include the construction of pipelines from the Yamburg gas field (directly north of Urengoy) and from the Zapolyarnyy gas field (northeast of Urengoy). Pipelines up to the northern Yamal Peninsula as well as the northern Kola Peninsula (the "North Star" project) also may be under consideration.

Several major areas of Arctic pipeline R&D will be reviewed in the following pages. The topics include programs for the development of (1) large-diameter, cold-resistant pipe, (2) laminated pipe and composite steel pipe materials, (3) compressor station technology, (4) welding, and (5) gas preparation. It should be noted that these topics do not exhaust the list of Soviet areas of activity. In general, the programs seek to reduce construction and operating costs and metal consumption while increasing throughput capacity.

Large-Diameter, Cold-Resistant Pipe

The development of cold-resistant steels and their use in manufacturing conventional large-diameter welded pipe for the far northern regions was undertaken in the 1970s by a large number of organizations, chief among which are the Central Scientific Research Institute of Ferrous Metallurgy imeni Bardin (TsNIIChermet); the All-Union Scientific Research Pipeline Institute (VNITI); the Novolipetsk, "Azovstal," and Orsk-Khalilovo metallurgical plants; and the Chelyabinsk, Volzhskiy, and Khartsyzsk tube rolling plants of the USSR Ministry of Ferrous Metallurgy(164). The lead developer of this steel was TsNIIChermet, the principal metallurgical research institute of the USSR Ministry of Ferrous Metallurgy.

The primary cold-resistant steel they developed is designated 09G2MF. This steel, which was designed specifically for 1,420-mm tubes, is described as low-perlite steel that is alloyed with manganese, niobium, and vanadium. Successful results from the industrial-test production of plate rolled out of this steel at the "Azovstal" Metallurgical Plant in Zhdanov and of 1,420-mm tubes made from those plates were reported in 1980(165). (The steel itself was produced by the Novolipetsk Metallurgical Plant.) About 500,000 m.t. of 09G2MF plate were produced at "Azovstal" in 1979.

Four other cold-resistant steel alloys—designated 08G2MFB, 14G2AFU, 09G2FB, and 17G1SU—also have been developed by TsNIIChermet, possibly in a joint effort with the Donetsk Polytechnical Institute (08G2MFB only) and the Novolipetsk Metallurgical Plant (08G2MFB, and 14G2AFU)(166). These alloys also are intended for large-diameter (1,420-mm) pipe for the Arctic regions. The Novolipetsk plant produces the 09G2FB and 17G1SU alloys(164).

A cold-resistant steel production technology was introduced at the Donetsk Metallurgical Plant in late 1980 where an experimental shop to produce such steel is under construction. Standard steelmaking will be employed until the raw steel is cast. At this point the steel is alloyed with powdered calcium-silicon to eliminate brittleness properties of the crystal boundaries. The experimental shop at the Donetsk plant is to produce 1 million m.t. of this steel per year for pipes and machine parts to be used in the far north(167).

In 1976 it was reported that the Cherepovets Metallurgical Plant also was producing a cold-resistant steel, but the designation of that steel was not given(168).

The Soviets also have developed the technology to heat-treat 1,420-mm tubes. The thermal treatment process would make it possible to increase the strength of the tubes by 20–25 percent, permitting a corresponding decrease in wall thickness(169). The treated pipe also is reported to have a high resistance to cold temperatures. The extent to which this technology has been put to use is not known, but it should result in substantial economies of steel.

Soviet capacity to produce large-diameter pipes has been very limited.* The "Azovstal" plant did not master the production of 1,420-mm tubes made of 08G2MFB steel on its "3600" rolling mill until 1977(171). Rolling of 09G2FB steel at Azovstal now has been mastered. The Khartsyzsk plant has begun the production of conventional 1,420-mm diameter tubes made of 09G2FB steel, but the volume of production is not known. In addition, the Khartsyzsk plant is producing 1,420-mm diameter laminated pipe (discussed below).

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*The USSR is, however, the world's leading producer of steel tube. In 1983 it produced 18.7 million m.t. of steel tube, of which roughly 60 percent probably would have been welded(1, 170).

A second "3600" mill is to be installed at the Western Siberian Metallurgical Plant in Novokuznetsk, but recent information indicates that there are serious delays in designing or installing this mill; completion of the mill before 1985 seems unlikely.

Finally, a "3000" mill is being installed in the Zhdanov Metallurgical Plant imeni Ilich. The "3000" mill is being obtained from several manufacturers in Czechoslovakia and has a rated output of 2.5 million m.t. of steel plate (5–15 mm) per year. The output of the "3000" mill will be used to make pipe for the northern gas and oil pipeline systems, but the diameter of these pipelines is not known to us.

Nonmonolithic Pipe Materials

Introduction. Since increases in pipe diameters beyond 1,420 mm are unlikely in the foreseeable future, the Soviets have sought to increase the throughput capacity of 1,420-mm pipe by increasing the pipe's ability to withstand greater operating pressures without increasing wall thickness. The Institute of Electrowelding imeni Paton in Kiev in the Ukraine has pioneered in this area.

Three developments merit discussion. First, there is the much-publicized laminated pipe in which the wall of the pipe consists of four to six layers of steel sheet. Laminated pipe was used in sections of the Urengoy-Uzhgorod export pipeline. The other two designs involve composite materials designated as "reinforced quasi-monolithic" and "quasi-laminated" metal.*

The development of these new pipe designs is intended to achieve a number of objectives. First, as mentioned above, the strength of the pipe will be increased, permitting an increase in operating pressures to as much as 120 atm, depending on the number of layers(173, 174). (Plans reported by V. Krotov, minister of power machine building, call for pipelines with only 100-atm pressure to be built starting in 1986 or 1987[168]). Second, crack propagation would be inhibited at the joints between the layers. Third, special alloying elements, such as niobium, would not be needed, resulting in lower production costs. Fourth, the use of laminated pipe should result in a reduction of metal consumption in the transport of north Tyumen gas by 15–25 percent and permit specific capital investment to be reduced by 20 percent. Fifth, gas cooling can be combined with laminated pipe, making it possible to transport double the volume of gas possible with the use of solid-wall pipe of the same diameter(174). Finally, laminated pipe sections can be used along with conventional pipe to suppress longitudinal crack propagation.

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*O. M. Ivantsov, a leading specialist in northern pipeline technology, reported that VNIIMetmash (see also p. 142 below) had developed a two-layer, spirally welded tube. We have seen no evidence of such tubes being produced, however(172).

Laminated Pipe. A November 1976 decree of the USSR Council of Ministers called for the construction of long-distance, high-pressure gas pipelines made of laminated tubes(168). In accordance with the decree, shops to produce such tubes were set up at the Vyksa and Khartsyzsk metallurgical plants. The first shop at the Vyksa plant began to produce 1,420-mm laminated tubes in late 1981. Production in 1982 was originally scheduled to reach 250,000 m.t. (the shop's rated capacity), but later goals lowered expectations to 80,000 m.t.(175). Four shops with the capacity to produce one million m.t. per year of 1,020-, 1,220-, and 1,420-mm laminated tubes were scheduled to go into operation here in 1984(176, 177). The Khartsyzsk plant also began production in 1981, but plans called for 1 million m.t. of laminated tubes for that year(178). The Soviets hoped to attain a total annual output of 2.8 million m.t. of laminated pipe by 1984(176).

Tests on a prototype laminated pipe were conducted in the vicinity of Vyngapur, south of Urengoy, in early 1978. The experimental pipeline was 200 meters in length and was tested at 0°C temperature and 75 atm pressure(179). A 5-km experimental pipeline was finished at the end of 1982 near the village of Beloyarskiy, which is located southwest of Urengoy and about 300 km south of the Arctic Circle(134). Tests on this experimental pipeline had been successfully conducted by the end of 1982. The pipeline may have been 4.5 km in length and may have been designed by a consortium of R&D facilities, among which we should mention the All-Union Scientific Research Institute of Trunk Pipeline Construction (VNIIST), SKB "Gazstroymashina," the "Orgneftegazstroy" Project and Technological Institute (PTI), TyumenNIIGiprogaz, and the Paton Institute(180). The experience gained in these tests was to be put to use on the export pipeline where "hundreds of kilometers" of that pipeline were to be made of laminated tubes(134).

Reinforced Quasi-monolithic (RQM) Steel. This material was developed jointly by the Paton Institute and the Institute of Casting Problems (both subordinate to the Ukrainian Academy of Sciences), under the direction of B. Ye. Paton and B. I. Medovar (both of the Paton Institute). Also involved in the development were researchers from the Institute of Machine Reliability (under the Belorussian Academy of Sciences), the "Azovstal" Metallurgical Plant, the Belorussian Automotive Plant (BelAZ) (in Zhodino), and the Scientific Research Institute of Automotive Materials (in Moscow)(181, 182). The technology for producing RQM steel has been assimilated by the "Azovstal" plant(182).

RQM steel plates are produced by placing special sheet steel dividers lengthwise in the ingot mold before teeming the ingot with raw steel. RQM steel has the same strength characteristics as monolithic steel, but RQM's resistance to cracking during hydraulic and pneumatic destructive testing is substantially higher(183). RQM steel also is being considered for use in the beds of large-capacity BelAZ dump trucks.

Quasi-laminated Steel. According to B. Ye. Paton, the distinguishing features of this new class of composite materials is that newly developed manufacturing technologies have made it possible to program not only the degree of bonding between the separate layers, but also the topography of the bonding along the surfaces of contact(184). The basis of these new technologies is a phenomenon discovered by the Paton Institute in the early 1960s: spontaneous vacuum gaps between metallic plates and the so-called juvenilization (*yuvenilizatsiya*) of their surfaces. This discovery led to the development of autovacuum pressure welding, which now is widely used for the production of quasi-laminated metals. Quasi-laminated metals also can be produced by forging. By varying the force applied, one can vary the degree of bonding between the layers. Sufficiently powerful forging can result in a nearly monolithic plate. One advantage of quasi-laminated metal is that it can be produced from layers of different alloys selected so as to impart specific properties to the resulting structure.

The six Urengoy pipelines to be built between 1981 and 1985 will require the construction of 174 compressor stations. Both foreign and domestic equipment will be used. Twenty-five-MW compressors and related technology for the Urengoy-Uzhgorod export trunkline are being purchased from Western European manufacturers (primarily from Dresser France SA, Creusot-Loire, Mannesmann, John Brown Engineering, Ltd., AEG-Telefunken, and Nuovo Pignone). The remaining compressor stations will consist of clustered Soviet 6- and 10-MW compressors produced specifically for such purposes, as well as converted aviation and ship turbines(185). A few of the new Soviet 16- and 25-MW compressors also may be used.

Development of more powerful domestic gas-pumping turbines, necessitated by the shift to larger-diameter pipelines operating at higher pressures, was called for in the main directions for the Tenth Five-Year Plan (see appendix A, item 1.h.). As a result, several new turbines are now in the industrial production stage. The U.S. embargo on technology for the export pipeline apparently has led the Soviets to redouble their efforts to finalize the development of these turbines.

The most significant Soviet development programs are (1) the 25-MW turbine designated GTN-25, which was designed by A. L. Kuznetsov at the Production Association (PO) "Nevskiy zavod" imeni Lenin in Leningrad, (2) the GTN-16 (16 MW) developed by the PO "Turbomotornyy zavod" in Sverdlovsk, (3) the GTA-TS-16 (also 16 MW), which uses rebuilt aircraft turbines, and (4) the GPU-10 and GPU-16, which use marine turbines. The first three have been designed for eventual use on 1,420-mm pipelines operating at upward of 120 atmospheres; the intended use of the marine turbine-based units is not known to us.

The first GTN-25 prototype gas turbine was produced by Leningrad's PO "Nevskiy zavod" in 1977 at Novgorod(186, 187). (See figure 6.) The unit had a nominal power of 30 MW. A second prototype was produced by the PO "Turbomotornyy zavod" in Sverdlovsk in 1979. The nominal power of this second prototype was 25 MW(188). Other reported key design specifications of the two gas turbines are(188):

	PO "Turbomotornyy zavod"	PO "Nevskiy zavod"
Efficiency rate, %	31	29.4
Gas capacity, kg/sec	103.0	175.0
Gas temperature at input to turbine, °C	1020	890

The GTN-25 was designed with the future development of a 40-MW unit in mind. According to one Soviet source, 80 percent of the subsystems and parts used in the GTN-25 are of a "unified design" that will facilitate the design and production of the 40-MW unit(189).*

Series production of the GTN-25 originally was scheduled for 1983, but one Western source reports that by mid-1982 four turbines had been completed and parts for nine others had been produced. The Soviets report construction of fourteen units as of November 1983(190). The first GTN-25 was to be fielded in December 1982(191) However, it is unlikely that production of the GTN-25 will reach a level sufficient to have much of an impact on the export pipeline construction until 1984. The Soviets tend to be relatively better at design than they are at mastering the series production of new technology, which usually entails cooperation of diverse agencies with little incentive for the latter to cooperate fully. Nonetheless, the needed production capability should be realized in the near future. Three plants in Leningrad as well as the PO "Turbomotornyy zavod" are now producing the GTN-25(190). In addition, it was reported in early 1983 that West Germany's AEG-Kanis had received the blueprints for the GTN-25 along with a U.S. $100 million order for turbines to replace the embargoed General Electric turbines(192).

The GTN-16 (16.5 MW), although less publicized and smaller than the GTN-25, appears to have the more sophisticated design from a technical point of view. Key reported design specifications of the GTN-16 are(188, 193):

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*Unified design is a common Soviet manufacturing practice. It can be seen in the commonality of parts and subsystems of Soviet fighter aircraft as well as many civilian products, such as trucks. Unified design permits reductions in the variety of goods produced, cuts design costs, and facilitates repair. In a sense, the lack of a marketplace has enabled Soviet producers to engage in cost-minimizing behavior to an extent usually not possible in a competitive economy.

Efficiency rate, %	29
Gas capacity, kg/sec.	85.0
Gas temperature at input to turbine	910°C

Based on published drawings of the power turbine and compressor, it is probable that the GTN-16 incorporates aviation compressor technology(193). The unit appears to be well-designed, although designed for long operating life and reliability rather than maximum performance (the rated service life is 100,000 hours). The design aims at maintenance-free operation and incorporates many backup systems in case of failure. The turbine temperature (910°C) is moderately high, but in a range where economical alloys can be used. In general, the design is more conservative than that of GE compressors to be replaced but should prove adequate for Soviet needs.

The GTA-TS-16 has entered series production at the Sumy Machine Building Production Association (194, 195). This compressor incorporates converted turbofan aviation engines used in the Tupolev Tu-154 and Ilyushin Il-62 passenger aircraft. The engines are reported by a Western source to have a thrust of 23,100 lbs.(194). Aircraft engines also are being converted for use as gas pipeline compressors at the Kazan Engine Building Association, which is probably subordinate to the USSR Ministry of the Aircraft Industry, one of the defense-industrial ministries(196). In December 1983 it was reported that the Kuznetsov OKB had developed a 16-MW gas-pumping unit designated the NK-16ST based on the NK-8-2U aviation engine used in the Tu-154 aircraft(197). The NK-16ST was said to have been developed on a "crash basis" under the direction of Academician N. D. Kuznetsov, the head of the OKB. The relation between the NK-16ST and the GTA-TS-16 is not known; both are rebuilt turbines taken from or designed for Tu-154 aircraft, but they may be parallel developments. The Kutznetsov OKB also is reported to be working on a 25-MW unit based on a different aircraft engine(197). The use of aviation engines should save the Soviets considerable resources, especially scarce alloying elements, and will make advanced defense-industry generated technology available to the gas industry.

Development of gas-pumping units based on marine engines is under way at the All-Union Scientific Research and Project Institute for Gas Transport (VNIPITransgaz) and the All-Union NPO "Soyuzturbogaz"(198). The earliest known member of the series, the GPU-10-01 (presumably having 10 MW of capacity), is said to be equal

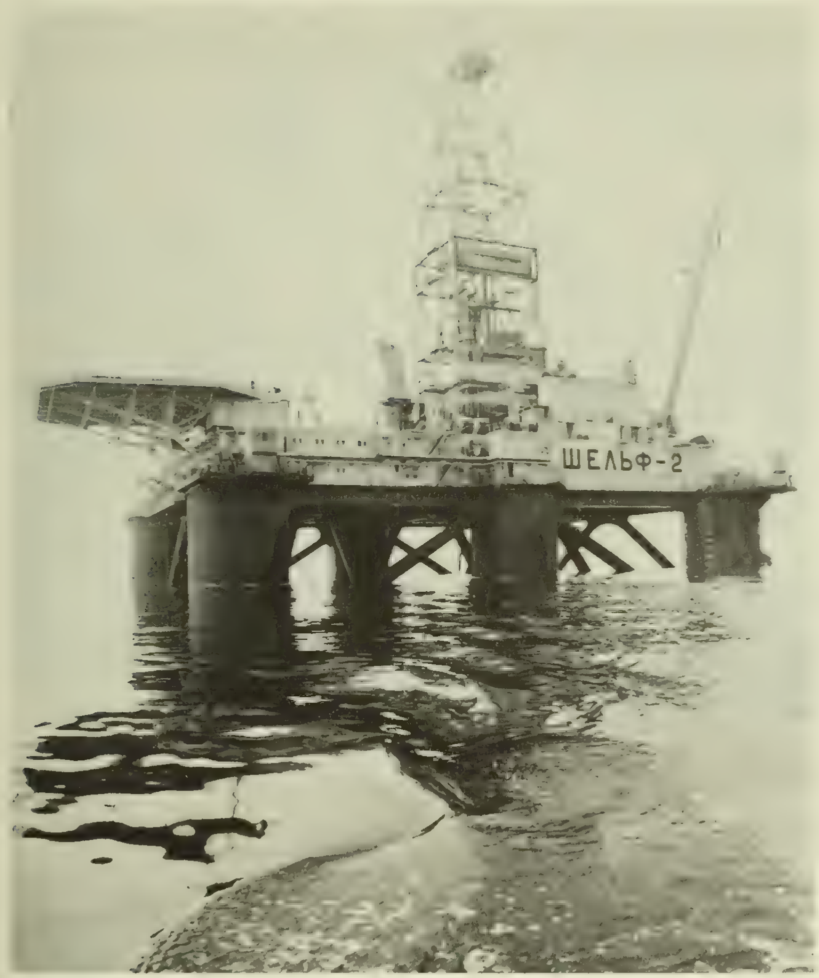

Figure 5 Shelf-2 Drilling in the Caspian Sea (photo credit: TASS from SOVFOTO)

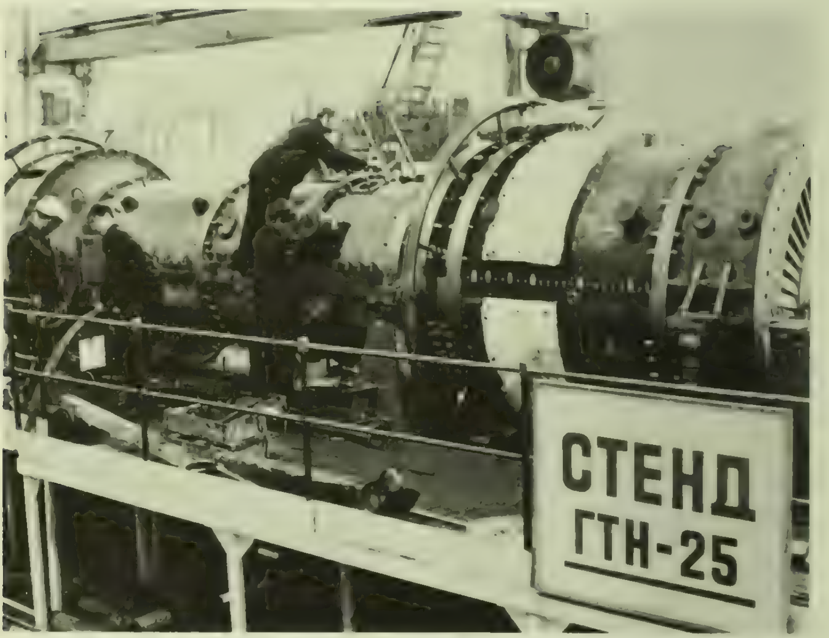

Figure 6 The GTN-25 Gas-Pumping Unit (photo credit: TASS from SOVFOTO)

to the best domestic and foreign analogs. A modification of this unit, known as the GPU-10-11, was tested in 1982. The new unit is reported to have an improved layout and an increased degree of modular design, which facilitates repair and operation. Future efforts are to be aimed at incorporating some of the developments in the GPA-TS-16 in a GPU-10 design of smaller size and the development of a GPU-16 unit (presumably of 16 MW).

Given these recent Soviet achievements, continued imports of Western compressors by the Soviets should be interpreted as reflecting urgency or constraints on production capacity and not the technical inability to substitute away from Western technology in this area.

Welding Technology

The most important Soviet welding activities within the framework of the present discussion are the development of the "Sever" (North) automatic electric-contact welding complex for 1,420-mm diameter pipe and the "Styk" complex for 1,220- and 1,420-mm diameter pipe, both of which were developed by a team of facilities under the leadership of the Institute of Electrowelding imeni Paton.

The first experimental unit of the "Sever-1" was developed in 1974 by the Paton Institute, VNIIST, and the Kiev Branch of SKB "Gazstroymashina"(199, 200). It was field-tested between 1975 and 1977 and was subsequently used in industrial-test conditions on the "Soyuz" pipeline project. In 1978–79 the Sever-1 was used to weld 32 km of pipe along the Urengoy-Chelyabinsk pipeline(200). By 1982 the Sever-1 was in production at the Pskov Heavy Electrowelding Equipment Plant, south of Leningrad(199).

The Sever-1 consists of a self-propelled, inside-the-pipe welder (the K-700), a mobile diesel-fueled electric power station (the ESD-1000), an external burr remover, a device for cleaning the pipe ends, a pipe layer, and an ultrasonic weld inspection laboratory(200). The Sever-1 can operate in temperatures as low as –40°C and has an average productivity of six to seven seams per hour. The quality of the unit is such that U.S. and Japanese firms are reported to have purchased licenses for it(191).

The "Styk-1" was developed by the Paton Institute, VNIIST, and the Kiev Branch of SKB "Gazstroymashina"(201, 202). The Styk unit consists of a self-propelled welder on a TT-4 skidding tractor equipped with a three-phase power source, welding rectifiers, two thyristor drives, and other equipment. The Styk-1 was used to make 174 weld pipe joints on the "Soyuz" gas pipeline(201).

A "Styk-2" for welding 325 – 1,020 mm pipe also has been developed. The Styk-2 was field-tested near Moscow, and series production is scheduled at an unspecified point in the future(183).

The Soviets also are developing spirally welded tube technology. The program is being headed by VNIIMetmash with assistance from Mannesmann in West Germany(203). VNIIMetmash is developing the technology to produce spirally welded tubes up to 24 mm in wall thickness.

Gas Preparation

The Gipropetsgaz Institute in Leningrad recently has designed a high-capacity gas-chilling station that is apparently intended for use in the Urengoy region(204). (The gas, although originating in a subarctic region, is relatively warm by virtue of its location deep within the earth.) Warm gas cannot be transported as efficiently as chilled gas and, in addition, acts to warm the pipe and its supports, resulting in thawing of the permafrost, which, in turn, may lead to movement of the pipe. Calculations show that throughput can be increased by 50 percent if the gas is cooled to –28°C(205).

Other new proposals for preparing natural gas for transport involve cooling the gas, transport of gas hydrate, and liquefaction of gas(206). The Urengoy-Chelyabinsk pipeline was designed with the possibility of gas chilling in mind(206, 207).

Key Organizations and Personalities

Pipeline R&D is carried out at over one hundred industrial, academy, and educational organizations. The lead organization in pipeline R&D is the All-Union Scientific Research Institute of Trunk Pipeline Construction (VNIIST). This institute, which is subordinate to the Ministry of Oil and Gas Industry Enterprise Construction, performs pipe research on a wide range of tasks, including welding, strength of materials, corrosion, pipe-laying equipment, gas preparation, soil-pipeline interactions, X-ray and gamma-graph control, and modular construction techniques(207). VNIIST worked with the Paton Electro-

Table 8 Organizations and Personalities Engaged in Arctic Pipeline R&D

Organization (name, subordination, location)	Area of R&D
All-Union Scientific Research Institute of Trunk Pipeline Construction (VNIIST), Ministry of Oil and Gas Industry Enterprise Construction, Moscow A. Zinevich, director(1978)	Pipeline design, welding, corrosion, pipelaying equipment design
"Soyuztransprogress" Association [fnu] Zhdanovich, director (1978)	
Soyuzgazproyekt (expansion unknown), Donetsk	Chief designer of the Urengoy export pipeline
Institute of Permafrost, Siberian Division, USSR Academy of Sciences, Yakutsk P. I. Melnikov, director (1978)	Permafrost studies, pipeline supports
All-Union Scientific Research Pipeline Institute (VNITI)	
Institute of Physical-Technical Problems of the North, Yakutsk	Permafrost, pipeline supports, corrosion
Institute of Electrowelding imeni Paton, Ukrainian Academy of Sciences, Kiev B. Ye. Paton, director	Welding, laminated pipe, composite pipe materials
SKB "Gazstroymashina," Ministry of Oil and Gas Industry Enterprise Construction	Welding and construction equipment
Production Association "Nevskiy zavod" imeni Lenin, Ministry of Power Machine Building, Leningrad	Development and production of compressor stations
Production Association "Turbomotornyy zavod," Sverdlovsk	Development and production of gas-pumping turbines
Kiev Branch, SKB "Gazstroymashina"	Compressor stations
YuzhNIIGiprogaz [expansion unknown], Donetsk	Compressor stations
Central Scientific Research Institute of Ferrous Metallurgy imeni Bardin (TsNIIChermet), USSR Ministry of Ferrous Metallurgy (Minchermet), Moscow	Cold-resistant steels
All-Union Scientific Research and Project-Design Institute of Metallurgical Machine Building (VNIIMetmash), Mintyazhmash, Moscow	Cold-resistant steel, spirally welded tubes

Table 8 (continued)

Organization (name, subordination, location)	Area of R&D
Donetsk Metallurgical Plant, Minchermet	Cold-resistant steel
Vyksa Metallurgical Plant, Minchermet	Rolling of laminated pipe
Khartsyzsk Metallurgical Plant, Minchermet	Rolling of laminated and conventional large-diameter pipe
"Azovstal" Metallurgical Plant, Minchermet	Rolling cold-resistant, large-diameter pipe
Novolipetsk Metallurgical Plant, Minchermet	Cold-resistant steel
Orsk-Khalilovo Metallurgical Plant, Minchermet	Cold-resistant steel
Petrochemistry Sector, Ukrainian Academy of Sciences	Corrosion protection
Ukrainian Scientific Research and Design Institute for Development of Machinery and Equipment for Processing Plastics, Rubber, and Synthetic Leather (UkrNIIPlastmass), Kiev	Corrosion protection

welding Institute and VNIIMetmash on the development of laminated pipe and with the Paton Institute on pipe welding. VNIIST also worked with the Karpov Physical Chemistry Institute, the USSR Academy of Sciences' Institute of Physical Chemistry, and the Academy of Communal Economy on pipeline corrosion caused by soil. Key facilities engaged in Arctic pipeline R&D, including metallurgy and the development of pipe-rolling technology, are briefly described below and listed in table 8.

The Paton Institute, which is subordinate to the Ukrainian Academy of Sciences, has developed a laminated pipe that is resistant to cold and can operate at pressures of up to 120 atmospheres (see the discussion above). The institute has worked extensively on pipe welding technology and has worked with facilities of the Ministry of the Electrical Equipment Industry and the Ministry of Oil and Gas Industry Enterprise Construction on resistance welding of 1,420-mm pipe.

The Central Scientific Research Institute of Ferrous Metallurgy imeni Bardin (TsNIIChermet) has developed cold-resistant pipe steels that are now being produced by the Novolipetsk and Orsk-Khalilovo Metallurgical Plants.

The All-Union Scientific Research and Project-Design Institute of Metallurgical Machine Building (VNIIMetmash) has been engaged in the development of production technology for the manufacture of laminated, spirally welded pipe with wall thicknesses of up to 27 mm.

The Institute of Permafrost, which was directed by P. I. Melnikov in the late 1970s, has worked on permafrost-zone pipeline supports in which the support is kept cool to prevent melting of the permafrost.

Evaluation

Soviet demand for Arctic natural gas as a domestic energy resource and as a foreign-exchange generating export began to grow before the USSR was in a position to exploit the Arctic region on a large scale without substantial Western assistance. The reliance on Western technology should not be misinterpreted, however. As of the end of 1975, before the United States had completed the Alaskan oil pipeline, the Soviets had gained considerable experience in producing equipment and materials for Arctic region pipelines and had constructed two pipelines out of the Medvezhye gas field and had another pipeline under construction. By the end of 1980 two more pipelines had been built out of Medvezhye and a third was under construction, a pipeline out of Urengoy had been constructed, and a pipeline between Messoyakha and Norilsk had been completed. Soviet use of Western technology in the export pipeline project has been necessary primarily because of the *magnitude* of the effort, and only secondarily because of Soviet technical backwardness, since all the pipelines could have been built without Western technology if several years of schedule delay and lower reliability were acceptable. In addition, the Soviet R&D programs intended to substitute domestic 1,420-mm pipe and compressor technology for imported products have been given a shot in the arm by U.S. attempts to block completion of the export pipeline. Within the next few years, the USSR should have the capability to produce several million tons of 1,420-mm cold-resistant tube per year. Three different domestic gas-pumping units have been developed and one—the GTN-25—is now being produced by the

"Nevskiy zavod" Production Association in Leningrad, while others soon will be produced by AEG-Kanis in West Germany.

The pipeline R&D and production programs enjoy strong support from both the Communist Party and the Soviet government and can be expected to achieve substantial progress during the current five-year plan (1981–85).

Chapter 5 Options for the Use of Eastern Lignite and Sub-Bituminous Coal

Despite the Soviet Union's rich endowment of coal (greater resources than any other country and second only to the United States in terms of proven reserves), it recently has been unable either to increase coal output as planned or to increase coal's share in total energy production. In the early 1970s energy planners were considering a substantial increase in the share of coal in the fuel and energy balance, but currently it appears that coal is being deemphasized in favor of natural gas as a substitute for the relatively more scarce crude oil, both as a domestic energy source and as an export commodity. The reasons for this shift in policy appear to be, first, the relative inconvenience of coal transport and use compared to natural gas; second, the high and rising cost of mining in the western coal-producing regions (e.g., the Donets and Moscow basins) because of depletion and worsening geological conditions; and, third, the great distances between the vast coal reserves of Siberia and the consuming centers of the European USSR. Currently, the huge lignite deposits of Kansk-Achinsk and the sub-bituminous coals of Ekibastuz are the most accessible and cheapest coals in the east, but their low caloric content per unit of weight limits the economic radius of transport of run-of-mine coal. The assimilation of these coals into the national energy balance largely depends on the development of technologies to enrich or transform them sufficiently to permit economical consumption west of the Urals.

The purpose of this chapter will be to examine Soviet R&D efforts directed toward these goals and to assess their prospects for success. This chapter will begin with background material on the Soviet coal

The technical discussions presented in the last two-thirds of this chapter evolved from two previous works by the authors. See references (1) and (2).

industry and on the geography of coal in order to provide the reader with an understanding of the basic problems confronting the economic planners with respect to coal development. The various options proposed by Soviet scientists and economists for the use of eastern coal will then be discussed, followed by in-depth discussions of the major R&D programs supporting one or another of these options. Coal processing—including preparation (cleaning), enrichment, and conversion into gaseous and liquid products—will be discussed first, followed by a review of the R&D on pipeline transport of coal or coal products.

Coal Industry: Current Situation

Coal Production

After nearly constant growth in annual output* throughout the post-World War II period, the production of Soviet coal leveled off in 1978 at roughly 724 million m.t.(3). Production declined to 704 million m.t. by 1981, recovered to nearly the 1979 level in 1982 (718 million m.t.), but again fell by 2 million m.t. in 1983 to 716 million m.t.(4) and again to 712 million m.t. in 1984(5). The plans for the Eleventh FYP call for an increase in output to 775 million m.t. by 1985(6). The goal for 1985 has no doubt been revised downward due to recent performance, but we have not seen any new targets. National and basin-by-basin production in five-year increments is shown in table 9.

Surface mining of coal as a percentage of total output is low relative to other Soviet mining industries, but it has been rising. In 1970 surface mining accounted for only 27 percent of total output of coal, but the share had risen to roughly 39 percent by 1981(10). (The plan for 1985 calls for a slight increase to 40.6 percent[11].)

Production of coking coal accounted for 27 percent of total output in 1970 but fell to 26 percent by 1977(12). Figures on coking coal output since 1977 are not readily available, but data on output at the major coking-coal producing basins reported in *Soviet Geography: Review and Translation* indicate declines in output in the great

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*Soviet coal output is reported in terms of run-of-mine coal, i.e., before cleaning and drying. Output is therefore somewhat overstated.

Table 9 USSR Coal Production (million m.t. of run-of-mine coal)

Basin	1965	1970	1975	1980	1985 (plan)
USSR total, of which:	578	624	701	716	775
European basins:	265	276	280	257	258
Donets	206	218	222	204	210
Pechora	18	22	24	28	28
Moscow	41	36	34	25	20
Eastern basins:	126	156	210	245	298
Kuznetsk	96	113	134	141	154
Kansk-Achinsk	14	18	28	35	48
Ekibastuz	14	23	46	66	84
South Yakutsk	2	2	2	3	12
Eastern basins shown as a share of total production	21.8%	25.0%	30.0%	34.2%	38.5%

Sources: 1965, reference(3); 1970 and 1975, reference(8); 1980 and 1985, reference(9).

Donets and Kuznetsk basins, stagnation at the Karaganda basin, and slight gains at the smaller Perchora basin(7).

Table 9 shows the production difficulties in many of the large, but old, mining areas (Donets, Moscow, and Pechora). Soviet strategy to offset these difficulties is to expand the output of coal east of the Urals, particularly at the Kansk-Achinsk and Ekibastuz basins. Production at Kansk-Achinsk stood at 31.6 million m.t. in 1977, or about 4 percent of Minugleprom output that year. By 1982 Kansk-Achinsk output had grown to roughly 37 million m.t., or 5 percent of total output. The big push in Kansk-Achinsk coal output, however, will not come until the 1990s(7). Estimates of Kansk-Achinsk output recently have been set at 350-400 million m.t. per year in the midterm, and 1 billion m.t. per year at full development(13).

Ekibastuz output stood at roughly 66 million m.t. in 1980, roughly 9 percent of Minugleprom output, and was scheduled to increase to 84 million m.t. by 1985, or almost 11 percent of planned output(7). Production is planned to rise to 150 million m.t. per year by 1990, with an eventual rise to 170 million m.t. afterward(14).

Long-range plans thus appear to call for eastern coal output amounting to perhaps one-third to one-half of total current output by the end of the century. This seems ambitious to us given the insufficient level of investment in the industry during the 1970s and the technical problems associated with the transport and use of those coals.

*The Geography of the Soviet Coal Industry**

Coal Reserves

The Soviet Union has vast coal reserves amounting to nearly one-half of total known world deposits. The most recent survey of Soviet coal reserves was completed in 1968. That survey set total coal reserves in the USSR at 6,800 billion m.t.(15), of which 427 billion m.t. were included in reserves for economic planning purposes and 256 billion m.t. were classed as "industrial reserves"—i.e., considered suitable for extraction under current technical and economic conditions(15). At current rates of extraction, coal included in the 1968 figure for industrial reserves alone should last for roughly 350 years.

Industrial reserves of hard coal were set at 147 billion m.t., and brown coal (lignite) industrial reserves were estimated to be 108 billion m.t. Of the hard coal reserves, roughly 66 billion m.t. are of coking quality(16).

Data on industrial reserves at the major coal basins are given below. Figures are from V. A. Shelest and reflect the 1968 survey data(16).

The Major European Coal Basins. The Donets, Moscow, and Pechora coal basins, which are west of the Ural Mountains, have accounted for roughly 40–45 percent of coal production in recent years, but contain only about 5 percent of total coal resources of the USSR and roughly 20 percent of the industrial coal reserves. Soviet exploitation of these fields has been heavy relative to their reserves, and the fields are showing signs of increasing depletion and decreasing economic attractiveness.

The famous Donets Basin, which contains 40.4 billion m.t. of industrial reserves, has long been a major supplier of coking coal for the Soviet iron and steel industry because of its high heating value (6,000 kcal/kg) and chemical structure. But the remaining coal in the Donets Basin is in deep, narrow, dipping seams; ten mines have already reached a depth of one kilometer(17). The cost of this coal consequently has been rising, and this has led to reductions in its market area. Production in the basin declined after the mid-1970s but picked up again in 1982(7). The maintenance of production in the basin has required the bulk of the coal industry's investment funds in recent years; other (and more productive) basins, such as Kansk-Achinsk and Kuznetsk, consequently are being denied the resources necessary for their planned expansion(18).

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*Readers desiring a comprehensive treatment of the geography of the Soviet coal industry are encouraged to read references (2) and (3).

The Moscow Basin (industrial reserves equal 4.8 billion m.t.) has long been uneconomical to mine, and its coal is high in ash and sulfur content. Production in the basin peaked several years ago, and substantial declines are expected from now on.

The Pechora Basin (7.9 billion m.t. of industrial reserves) lies largely above the Arctic Circle, as a result of which Pechora mines are extremely difficult to operate. The basin in recent years has had difficulty meeting its plan targets, but because the coal is of high quality, expansion of output to 31 million tons by 1990 is planned, although increases in output before 1985 are unlikely, due to failures to compensate for depletion with new mine construction.

The Major Central Siberian Coal Basins. Siberia contains vast deposits of coal varying in quality from the coking coals of the Kuznetsk and Southern Yakut basins to the low-grade lignites* of the Kansk-Achinsk Basin. Siberia's coal reserves comprise roughly 94 percent of the coal in the USSR(19), and over 98 percent of the Soviet coal that is suitable for strip mining(20). Much of the predicted coal in Siberia, however, is in hostile and difficult-to-access areas, such as the Zyryanka and Taymyr basins, which straddle or lie above the Arctic Circle, the vast Lena Basin (predicted to contain one-third of the USSR's coal resources), and the Tungus Basin stretching from near Krasnoyarsk in the south to Norilsk, north of the Arctic Circle. Better situated are the large coal deposits in the Kuznetsk, Ekibastuz, and Kansk-Achinsk basins. Coal from these areas is cheaper to extract than coal in the European USSR, but it is remote from the large industrial centers.

The Kansk-Achinsk Basin covers 65,000 km^2 of area, mainly in

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*Lignites are immature coals that represent a transitional form between peat and sub-bituminous coal. Lignites are brown or black in color, with the brown lignite being the more immature. The Soviets call the Kansk-Achinsk lignites "brown coals" (*buryye ugli*). The terms "lignite" and "coal" have been used interchangeably with respect to Kansk-Achinsk coal.

Krasnoyarsk Kray along the route of the Trans-Siberian Railroad. The basin contains an estimated 1,200 billion m.t. of lignite to a depth of 1,800 meters, including 601 billion m.t. within 600 meters of the surface(21). (Industrial reserves are set at roughly 73 billion m.t.) Approximately 115 to 140 billion m.t. of coal are suitable for strip mining, an amount equivalent to two-thirds of the USSR's strip-mineable coal(22). The overburden is easily removed, making Kansk-Achinsk lignite one of the cheapest fuels to produce in the USSR(23). A ton of Kansk-Achinsk lignite costs one-seventh to one-eighth as much to extract as an average ton of coal in the RSFSR and one-half to one-fifth as much as a ton of strip-mined coal elsewhere in the USSR(24, 25).

Development of the Kansk-Achinsk Basin has been slow due to a lack of markets. (Currently only two of six deposits are exploited with a third under development(26).) Local coal demand is minimal, and the basin is situated between two large basins (Kuznetsk to the west and Irkutsk to the east) capable of satisfying coal demand in their areas. However, roughly 28 million m.t. of Kansk-Achinsk lignite were mined in 1975, and output was expected to reach 48 million m.t. a year in 1985. The big push in output should come in the 1990s at the earliest. In the mid-1970s about 90 percent of the basin's output was used locally(27).

The quality of Kansk-Achinsk coal is poor: like other lignites, it has a low heating value (2,800–3,900 kcal/kg depending on the deposit); a high moisture content (31–39 percent); and low mechanical strength. It has a low sulfur content (0.1–0.9 percent) and low ash content (6–13 percent), but the ash forms a slag during combustion (see p. 157, below). Run-of-mine Kansk-Achinsk lignite tends to freeze in cold weather, due to its high moisture content, and tends to self-ignite if dried. The low caloric value of run-of-mine Kansk-Achinsk lignite per unit of weight makes it uneconomical to transport beyond roughly 1,500–2,000 km or possibly even 500 km, depending on one's assumptions about transportation costs and the availability of alternative fuels(27, 28).

The Ekibastuz Basin, located in the northeastern part of the Kazakh SSR, contains 7.4 billion m.t. of industrial reserves of sub-bituminous coal(29). (Ekibastuz is not, strictly speaking, in Siberia, but it is a major coal basin and lies east of the Urals.) The high ash content of this coal (as high as 48–56 percent in some cases), as well as its low heating value, discourage its long-distance transport. Some Ekibastuz coal currently is being transported by rail to the Urals region where it is competitive with natural gas(30). A major portion of Ekibastuz coal output eventually will be used locally for electrical power generation, with ultra-high voltage (UHV) power transmission to the Urals or the Center. (The "Center" in Soviet parlance refers to Moscow and the surrounding areas.) Coal production in the Ekibastuz Basin increased from nearly 46 million m.t. in 1975 to 66 million m.t. in 1980. Yearly production once was scheduled to be increased to 70–75 million m.t. by 1980 and 150 million tons by 1990(31), but in fact may peak at 100–110 million tons(27). Figure 8 shows the ERP-2500 rotary excavator, which has a capacity of 2,500 m.t. per hour, in the "Bogatyr" surface mine at Ekibastuz.

Coal has been mined at the Kuzbass for decades. In 1975 estimated industrial reserves of Kuzbass coal stood at approximately 59.6 billion m.t., including lignite and high-quality coking coal. Kuzbass hard coal has twice the caloric value of Kansk-Achinsk lignite, is less costly to mine, and is closer to western consumption centers, making long-distance transport of it more attractive economically than Kansk-Achinsk lignite. Approximately one-third of the output is now consumed in the production of metallurgical coke, and the share is expected to rise to one-half by 1990(32, 33). Production in 1980 reached 141 million m.t. and was to be increased to 149 million m.t. in 1981, but production actually fell to 144 million m.t.(7). The Soviets believe the basin is capable of producing several hundred million m.t. of coal per year above the current level, but investment in the basin has been too low to expect any rapid growth in output in this century.

Options for the Use of Eastern Coal

Introduction

The coal strategy that developed in the early 1970s called for increases in eastern coal output and the rapid development of fuel and power complexes in Kansk-Achinsk and Ekibastuz (see appendix A, item 1.e). A number of options for the use of Kansk-Achinsk coal were developed and discussed in the Soviet economic literature. (See, in particular, reference [31].) The options involve either (1) burning the coal near the mines to generate electricity to be used locally or for long-distance UHV power transmission, (2) increasing the caloric value of the coal per unit of weight in order to improve its transportability, or (3) some combination of the two. The options for transporting the upgraded coal to the Center include rail and pipeline transport. The major options under consideration in the late 1970s included the following:

Option 1: Generation of electrical power and heat for regional use, combined with the siting of energy-intensive industry in the Kansk-Achinsk region.

Option 2: Option 1 combined with substitution of Kansk-Achinsk coal for Kuznetsk coal in power generation, freeing Kuznetsk coal for transport to the Urals and/or the Center.

Option 3: Generation of electricity at Ekibastuz and Kansk-Achinsk with UHV or cryogenic power transmission to the Center.

Option 4: Transport of clean or enriched Kansk-Achinsk coal to the Center by rail.

Option 5: Gasification of Kansk-Achinsk coal.

Option 6: Liquefaction of Kansk-Achinsk coal.

Option 7: Enrichment of Kansk-Achinsk coal to improve transportability.

Option 8: Transport of enriched Kansk-Achinsk coal to the Center by slurry or container pipeline.

An option will not be treated in detail here if (1) it is not directly related to the central theme of this chapter (improving the transportability of eastern coal—namely, Options 1 and 2), (2) it does not require substantial new R&D achievements before implementation can begin (Option 4), or (3) it involves technologies discussed in other chapters (Option 3). Therefore, Options 1, 2, and 3 will be treated only briefly in the immediately following material, while only passing reference to Option 4 will be made. (Option 3 will be treated in depth in chapter 6.)

Local Use of Eastern Coal (Option 1)

Fuel and Power Complexes. Large thermal electric power plants intended to supply local and regional needs and fired by local coal are already under construction in both the Ekibastuz and Kansk-Achinsk areas, as called for in the Main Directions for the Tenth Five-Year Plan (1976–80). (See appendix A, item 1.e.)

Originally, the first Ekibastuz State Regional Power Station (GRES) was to go on-line, and construction of a second GRES was to be started during the Tenth Five-Year Plan(35). Construction, however, has been lagging. The plans for the Eleventh FYP included a target for GRES No. 1 to be finished by 1983. (Seven out of the eight 500-MW units for this GRES were on line as of October 1983, with the eighth scheduled for completion by year's end[36].) Construction of the first unit at GRES No. 2 was to begin by 1983(37). Altogether, three stations are to be built at Ekibatsuz, with a fourth station in Southern Kazakhstan usually being counted as part of the program(38). In addition to the construction delays, the installed capacity has not been operating properly for a variety of reasons.

The Kansk-Achinsk Fuel and Power Complex, known as "KATEK," is being created to handle coal production, coal enrichment and conversion, and electrical power generation. The Party called for the development of the complex in its Main Directions for the Tenth Five-Year Plan; the formal start of KATEK came in a 1979 government decree(39). The Party's Main Directions for the Eleventh Five-Year Plan called for its accelerated development. (See appendix B, item 1.a.) Ten power stations are to be built at KATEK according to recent Soviet sources(41), but in April 1983 the journal *Soviet Geography* reported that their number had been reduced first to eight and more recently to five(7). The plans, therefore, are not clear at present. The stations to be built near the eastern deposits (Abansk, Irsha-Borodino) will be used for local power supply, while those in the western deposits (e.g., Berezovskoye) will supply power locally and to the Urals and eventually to the Center. The first western power station—the Berezovskoye GRES No. 1—now is under construction. The first of its eight 800-MW blocks was to go into operation in 1983(42), but work on the foundation for the main building did not begin until October of that year(36).

KATEK has been accorded the status of a national territorial-production complex; its development also is covered by at least two GKNT S&T programs, one calling for development of mining technology and mine capacity, and the other calling for creation of a synfuels base(40). (GKNT programs are discussed in chapter 2.) The mining technology program calls for the design and production of thirty-five new models of equipment, twenty-nine of which were to be ready for use before the end of 1985. Some thirty R&D facilities and production plants of seven ministries and agencies, including academy facilities, are involved in the effort. The leading institutes are the Institute of Mining imeni Skochinskiy and the UkrNIIProyekt (expansion unknown). Other participants include the Uralmash and Zhdanovmash production associations, the Novokramatorsk Machine Building Plant of the Ministry of Heavy and Transport Machine Building, and the Institute of Geotechnical Mechanics of the Ukrainian Academy of Sciences. The coal conversion program involves the activities of over 150 research, design, and production facilities of twenty-five ministries and agencies, including nineteen institutes of the academy system(40).

Although extremely costly, the siting of industry in Siberia, especially energy-intensive industries, is being seriously considered by Soviet planners and administrators. The Party's Main Directions for both the Tenth and Eleventh FYPs have called for the limiting of energy-intensive industrial activity in the European USSR and Urals regions (appendix A, item 3.a) and the siting of such activity in Siberia and Kazakhstan (appendix B, item 4.a). Such measures will necessitate a lengthy program to provide supporting services for the industries themselves and for the labor force.

Boiler R&D. A major problem connected with Option 1 (and Options 2 and 3) has been and continues to be the need to develop boilers that are suitable for burning the varied coals in the Ekibastuz and Kansk-Achinsk Basins. Although several suitable boilers already have been developed or now are in the development stage, future declines in the quality of both basins' coal will force the modification of existing boilers as well as the development of new ones.

Run-of-mine coal contains varying amounts of ash-forming minerals that are either combined intimately with the coal itself or are found as bands between the layers of coal. Coal preparation (crushing, washing, and drying) can remove much of the latter free mineral material, but some minerals will always be fed into the furnaces of coal-burning boilers. Depending on the nature and quantity of these minerals, this leads to degradation of boiler performance following the deposition of mineral deposits or slag on furnace surfaces. It is, in fact, the presence of ash that distinguishes the design requirements for coal-combustion processes from those for natural-gas or oil-combustion processes(43). The specific design solutions adopted depend on the coal to be burned and the quantity and nature of ash present. Ash content is highly variable—varying even within one deposit from place to place—and none of the presently used analytical methods can determine the exact nature of the ash or predict exactly how it will behave in the boiler. Therefore, a wide variety of designs will be required, each of which will depend substantially on the designer's "judgment"(43).

The major chemical components of Kansk-Achinsk and Ekibastuz ash are given below (average composition in percentage of total ash):

	Coal	
Oxide	Kansk-Achinsk(44)	Ekibastuz(45)
SiO_2 (A)	10 (to 30%)	62%
Al_2O_3 (A)	11	33
Fe_2O_3 (B)	29	2
CaO (B)	42 (20–60%)	1
MgO (B)	6	1

A = Acidic B = Basic

Kansk-Achinsk coal appears to be a particularly troublesome coal, one which would not be considered for large-scale use in boilers unless no other alternatives were available. The coal is characterized by a relatively low SiO_2 and Al_2O_3 content and a high CaO and Fe_2O_3 content. The latter two oxides, being basic oxides, act to lower the melting temperature of the coal ash(43). Kansk-Achinsk lignite, in fact, has the lowest ash melting point (950–1,000°C) of any Soviet steam coal currently in use(46). (Ash melting point is not defined; the reader should be aware that several ways to measure the melting point exist.) In addition, during combustion the CaO combines with sulphur to form anhydrite $CaSO_4$, which results in a sharp hardening of the ash deposits or slag. The relatively high iron content of the ash also is troublesome. Reduced molten iron in the furnace is difficult to remove and iron oxides tend to lower the ash melting point when present in quantity. (Kansk-Achinsk ash has a very low iron-calcium ratio (0.69), which also indicates a very low ash softening temperature[43].) Finally, pulverized Kansk-Achinsk lignite is explosive because of its low ash content (6–13 percent) and its high reactivity(47). Consequently, the major technical problems associated with burning Kansk-Achinsk lignite, especially Berezovskoye lignite, are the prevention of slagging on the screens (*ekrany*) and semiradiant heating surfaces, the formation of sulfated ash deposits on the convective heating surface, and accumulations and explosions of the coal fines in the fuel system(47).

Ekibastuz coal, on the other hand, has a relatively high ash melting temperature, and until now slagging in the boiler has not been a serious problem. The ash contains a high share of acidic oxides (SiO_2 and Al_2O_3) with only minor amounts of basic oxides (CaO and Fe_2O_3), which results in a high melting point of the ash(43, 45). The large amount of ash in Ekibastuz coal, which averages 38–43 percent(48), coupled with the predominance of SiO_2 and Al_2O_3 (in the form of the minerals kaolinite and quartz) leads, however, to abrasive wear in the boiler due to the high content of free silica(45). The ash content of Ekibastuz coal is expected to rise in the near future with the increased use of rotary-bucket excavators for mining (which could lead to an ash content of up to 55 percent) or with the opening of mines with poor quality coal(49). Analysis of the higher ash-content Ekibastuz coals indicates that a strong slag containing 50 percent ferrous oxides tends to form on the heating surfaces(45).

At present power stations using Kansk-Achinsk coal are using coal from the Nazarovo and Irsha-Borodino surface mines(47). Both coals have been successfully burned in the BKZ-320F AND BKZ-420F boilers made by the Barnaul Boiler Plant (BKZ)(46). The boilers employ an axis vortex, vertical prefurnace with tangential arrangement of burners and coal drying by flue gas. The boilers operate at a high combustion temperature and use wet-bottom slag removal. The high temperature and special aerodynamic design of the furnace combine to facilitate contact among the ash particles and the reduction of free calcium oxides in the volatiles by bonding the calcium with oxides of silicon and aluminum. This leads to the formation of stable aluminum and silicate compounds that reduces sulfation of the calcium.

This design, however, has proven to be inapplicable to the combustion of Berezovskoye coal in the large 800-MW power units at the Berezovskoye GRES-1, now under construction. The current solution to this problem is the P-67 boiler developed by the All-Union Heat Engineering Institute imeni Dzerzhinskiy (VTI); the Special Design Bureau (SKB) of VTI; the Podolsk Machine Building Plant imeni

Ordzhonikidze (ZIO); the Central Scientific Research Boiler and Turbine Institute imeni Polzunov (TSKTI), and the "Teploelektroproyekt" Institute (TEP).

The P-67 was described by D. L. Itman, Yu. L. Marshak, and Yu. A. Kharkin of VTI and I. A. Sotnikov and Yu. I. Okerblom of ZIO in a 1979 book(52). The technical design (*tekhnicheskiy proyekt*) specifications of the boiler incorporated the following features: *steam generation* (quantity = 2,650 m.t./hr; heat output = 1,730 Gcal/hr; pressure = 255 kg-force/cm^2; superheated steam temperature = 545°C); *reheat steam* (quantity = 2,186 m.t./hr; pressure = 37 kg-force/cm^2; temperature = 545°C).

The major design problem was concerned with slag removal. The problem is to be solved by the use of a relatively low combustion temperature with dry-bottom slag removal. A tangential furnace with a square cross section was used because of the favorable aerodynamics in such a furnace and because of the more even distribution of thermal fluxes along the perimeter of the furnace, which reduces the ash buildup on its surface. Multiple tiers of burners reduce the thermal stress around each tier and on the radiant surfaces in the combustion zone. The combustion temperature is estimated to be 1,250–1,260°C, which, coupled with other design features, it is hoped will ensure operation without severe slagging problems.

Research is now being conducted to reduce the size of the P-67 boiler (the top is about 90 m above the floor of the power plant). VTI and ZIO are working on a design incorporating dry-bottom slag removal, gas drying, and pulverizer-fans that could reduce the height by 20–23 m and the width by 12 m. Boilers of this design are to be installed at the Berezovskoye GRES No. 2(46).

Commercial use of Ekibastuz coal began in 1954. In 1981 there were over twenty generator blocks of 300- or 500-MW capacity (320 and 420 m.t. steam per hour boilers, respectively) in operation using Ekibastuz coal(46). Several boiler systems are in use including the PK-10 and PK-14 boilers, which have been redesigned to handle the high-ash Ekibastuz coal, and the BKZ 320-140, BKZ 420-140, P-39, and P-57 (apparently, also known as the PK-57) boilers designed specifically for this coal. The P-57 boiler with a steam production rate of 1,650 m.t. per hour is currently the top-of-the-line boiler and will be used with 500-MW power blocks; the PK-39 boiler for 300-MW power blocks, however, is more widely used(52).

The P-57 boiler was developed by VTI and ZIO in 1971, and the first boiler went into operation at the Troitsk GRES in 1974(48). The designers of the P-57 drew heavily on the experience gained in the operation of the PK-39 boiler, also designed by ZIO. The PK-39 was used at the Troitsk, Yermakovo, and Reftinsk GRESS with 300-MW power blocks(53). The P-57 also was described by D. L. Itman et al. in 1979(52). The technical specifications given by them are: *steam generation* (quantity = 1,650 m.t./hr; pressure = 255 kg-force/cm^2; temperature = 545°C); *reheat steam* (quantity = 1,350 m.t./hr; pressure = 40 kg-force/cm^2; temperature = 545°C). The P-57 was designed to burn Ekibastuz coal with a 35.9 percent ash content, 8 percent moisture content, and a heating value of 4,120 kcal/kg. The characteristics of this coal determine the main design features, which include dry-bottom slag removal and a T-shaped arrangement (main furnace flanked by two symmetrical downward passes). The temperature of the gases leaving the furnace is 1,200°C. The speed of the gases in the furnaces ranges from 7 to 8 m/sec, which is consistent with the prevention of excessive erosion of the furnace surfaces.

A modified P-57 boiler, designated P-57R, is to be installed at the Ekibastuz GRESS No. 2 and No. 3(46). The boiler, which in mid-1983 was still in the development stage at ZIO, will handle the higher ash content Ekibastuz coal that will be mined in the future (an average of 44 percent ash in the P-57R versus up to 39 percent ash in the P-57)(46, 54). Many of the design parameters of the two boilers are identical.

A 2,650 m.t./hour boiler adapted for Ekibastuz coal was being designed in 1977(55). The basic design parameters are identical with those of the P-67 described above.

The P-67 and P-57 (P-57R) boilers described here are modern in design but do not appear to be sophisticated compared with U.S. designs. The design is more "European" than American, as evidenced by the uncommon boiler arrangement (the T-shape) and the use of flue gas for coal-drying in the P-67, which is common for low-grade coals, such as Kansk-Achinsk lignite. The P-67 nonetheless is a notable achievement considering the difficult design problems posed by the mineral content of Kansk-Achinsk lignite.

Substitution of Kansk-Achinsk for Kuznetsk Coal (Option 2)

This option calls for Kansk-Achinsk lignite to be used for the generation of electric power and heat in Krasnoyarsk Kray and adjacent regions, the substitution of Kansk-Achinsk lignite for Kuznetsk coal in power generation, and the transport of Kuznetsk coal to the Urals, and, possibly, to the Center.

This option is heavily influenced by the extraction costs and relative calorific values of these two types of coal. As noted earlier, Kansk-Achinsk lignite lies near the surface and can be strip-mined at a very low cost. However, its calorific value per unit of weight is low so that it is not economically attractive to transport it great distances in untreated form.

Kuznetsk coal is also inexpensive to extract but has a relatively high calorific value (twice that of Kansk-Achinsk coal), making it more attractive to transport over long distances, even in untreated form. In 1971 Kuznetsk coal competed with Donets coal in a number of economic regions, including the Northwestern, Western, Volga-Vyatsk, Central, and Central Volga regions(30, 56). Today, however, Kuzbass coal has made deep inroads into the market areas for Donbass coal. Coke from Kuznetsk coal is significantly less expensive to produce than coke from Donets coal and is competitive with the latter anywhere in the USSR(57). Some 141 million m.t. of coal were mined from the Kuznetsk Basin in 1980, and it is believed that eventually several hundred million metric tons of coal can be mined annually. Almost half of the coal could be shipped westward(58).

Under this option, Kuznetsk coal would be transported to the Urals for use in electric power generation, as a boiler fuel, and as a source of coke.* Kansk-Achinsk lignite would replace Kuznetsk coal previously used in Siberia for power production(58). Such a substitution would be economically rational, because Kansk-Achinsk lignite is reported to be the cheapest source of power in Siberia. This option was recommended by the Institute of Economics and Organization of Industrial Production of the Siberian Division of the USSR Academy of Sciences at a 1977 conference in Kemerovo. The recommendation had the support of Gosplan USSR and "other central organizations"(58).

The Kuzbass is already linked to the Southern Urals by several rail lines, but the implementation of Option 2 on a scale typically envisioned would require the construction of a new railroad or massive improvements in existing railroads that would be almost equivalent to building a new railroad. Use of coal slurry pipelines (Option 8) is also possible, especially in view of expected increases in hydraulic mining in the Kuzbass in the next ten to fifteen years(34). VNIIPI Transprogress,* the Institute of Complex Transport Problems (IKTP), and USSR Gosplan's VNIIKTEP have developed two variants for pipeline transport of Kuznetsk coal to the Center that indicate that both capital investment and operating costs for pipeline transport are considerably less than for rail transport(59).

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*Some might question the long-run rationality of using high-grade Kuznetsk coal in electric power generation and boiler applications. But apparently only one-third of the output of the Kuznetsk Basin has been used to produce coke in recent years(32).

In the late 1970s Gosplan's Council for the Study of Productive Forces (SOPS) advocated the substitution of Kansk-Achinsk lignite for Kuznetsk coal for local power generation. It also advocates use of Kansk-Achinsk lignite farther eastward in Irkutsk Oblast and Bratsk-Tayshet Rayon(21).

UHV Power Transmission (Option 3)

An 1,150-kv AC transmission line running from Ekibastuz to Chelyabinsk is now under construction. The line was reported to have been completed through Kokchetav, about one-half of the way to Chelyabinsk, in December 1982. The line was to reach Chelyabinsk in 1985 and was to achieve rated capacity sometime afterward(7). A line running from Ekibastuz eastward to Barnaul also is under construction. The 700-km line will eventually tie up with the Kansk-Achinsk power distribution system. The line was scheduled for start-up in 1984.

Plans for a 1,500-kv DC "Ekibastuz-Center" power line have been adopted and a 1,500-kv DC test line has been constructed(60). The status of the actual line, construction of which was to have begun in 1978, however is uncertain. A 1978 source(61) indicates that construction actually began, but currently the line seems to be a dormant issue with emphasis now on completion of the 1,150-kv lines.

The Soviets also plan to use 50–60 million metric tons of Kansk-Achinsk coal annually for electric power generation and to move the electricity by UHV transmission. Kansk-Achinsk power stations will be linked to the existing Ekibastuz-Volga power transmission line by

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*VNIIPI probably stands for All-Union Scientific Research and Project Institute. The translation of *proyekt* (project) is problematical but indicates that the institute is involved in initial design of pipeline systems in addition to applied research.

an 1,150-kv AC line. In 1977 F. V. Sapozhnikov, a deputy minister of power and electrification, called for the development of 2,400–2,500-kv DC power lines capable of handling 40 million kw to link KATEK with the European regions of the USSR(25). However, the technical and economic feasibility of the proposed 2,500-kv DC "Kansk-Achinsk–Center" power line have not yet been proven. (UHV power transmission R&D is discussed in chapter 6.)

With regard to superconducting (cryogenic) power transmission, delays in completion of ENIN's test cable and a number of other factors will delay commercial application of this technology for long-distance power transmission until 1995 at the earliest. Superconducting transmission of electrical power from Kansk-Achinsk to the Center or Moscow Region, according to calculations of the Institute of Fossil Fuels (IGI), would be the cheapest option for utilizing Kansk-Achinsk lignite, in terms of variable costs(35). (Cryogenic power transmission R&D also is discussed in chapter 6.)

Rail Transport (Option 4)

Considerable attention has been given to the possibilities for transporting Siberian coal to the Center by rail. Three forms of coal could conceivably be transported: run-of-mine coal, semi-coke, or thermocoal. However, the first of these forms is not very attractive: run-of-mine Kansk-Achinsk lignite tends to freeze in rail cars during cold weather and has a low-caloric value per unit of weight. The ENIN semi-coke and IGI thermocoal processes were designed in large part to make long-distance transport of Kansk-Achinsk lignite economical, and both processes could be ready for large-scale commercial use within ten years.

According to I. P. Krapchin, IGI has developed and proved an additional method for improving the transportability of Kansk-Achinsk coal by rail by applying a protective film to it(62). In 1977 it was estimated that widespread adoption of this method could cut windborne losses by approximately 5 million m.t. per year (based on conditions expected to exist in 1980)(62). The coating consists of a water-tar mixture that is sprayed on the top of a loaded gondola car. The tar could be a by-product of the IGI thermocoal process described below.

We now turn to Soviet R&D supporting Options 5 through 8.

Coal Preparation

Introduction

Coal preparation (cleaning) involves the crushing, sizing, washing, and dewatering of run-of-mine coal in order to remove rock and other noncombustibles. Preparation of Kansk-Achinsk lignite would be required as an initial step in its conversion to liquid or gaseous forms. In addition, clean Kansk-Achinsk coal would facilitate the implementation of the four above-mentioned options as well.

Demand for clean coal is likely to grow in the future. The main directions for the development of the economy to 1985 and 1990 established by the Twenty-Sixth Party Congress call for increasing the quality of coal supplied to the economy and point out that increases in coal preparation capacity are to come largely through improvements in technology(63). (See also appendix B, item 1.e.)

Prospective Developments

The Institute of Solid Fuel Enrichment (IOTT) of Minugleprom has developed an autoclave unit wherein the conversion of coal is conducted in a saturated water steam under 14–20 atmospheres of pressure at a temperature of 140–200°C. Industrial tests of the process using lignite from the Irsha-Borodino surface mine at Kansk-Achinsk showed that the process reduced the moisture content of the lignite from 30–34 percent to 12–17 percent. In early 1981 an experimental-industrial facility with a capacity of 30,000 m.t. of run-of-mine coal per year was under construction at Irsha-Borodino(64).

Other developments under way at R&D facilities have been cited in the press or the coal industry literature, but few details on these developments are known. They should be mentioned, however, because Soviet R&D on coal preparation has led to impressive results, even by Western standards. For convenience, we have simply listed a number of these developments:

Development of inexpensive and effective apolar and heteropolar flotation reagents.
Flotation with use of ultrasonics and magnetic fields.
Use of fluidized-bed separation.
Development of methods for cleaning high-sulfur steam coals.

Development of methods for cleaning Kansk-Achinsk lignite.
Production of 1,000-m^3/hr flotation units.
Expanded use of pneumatic cleaning of lignites.
Production of vacuum-filters with filtering surfaces of 250 m^2.
Production of 350 m.t./hr sedimentation-filtering centrifuges.
Production of 500 m.t./hr wheel separators.
Production of pneumatic flotation machines based on a counterflow principle, with capacities of 1,000–1,500 m^3/hr.

*Key Organizations**

The primary R&D institutes in the field of coal preparation, all under the Ministry of the Coal Industry (Minugleprom), are listed below:

Institute of Solid Fuel Enrichment (IOTT).
Ukrainian Scientific Research Institute of Coal Enrichment (UkrNIIUgleobogashcheniya).
Donets Scientific Research Institute of Coal Enrichment (DonNIIUgleobogashcheniya).
Voroshilovgrad Branch of the "Giprougleavtomatizatsiya" Institute.
Kuznetsk Scientific Research Institute of Coal Enrichment (KuzNIIUgleobogashcheniya).
Institute of Coal Machine Design.

Several university-level technical institutes of the various ministries of higher and specialized secondary education (MVSSO) that are located near the major coal-producing basins are providing supporting R&D.

Coal Gasification (Option 5)

Introduction

This subsection and the two following it describe R&D efforts that, in the Eleventh FYP (1981–85), were considered the major coal R&D thrusts by the Coordinating Council for the Problem "Synthetic Fuel," which probably leads the efforts under the GKNT synthetic fuel program. As of mid-1980, A. Ye. Sheyndlin, the director of the

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*The discussion in this section benefited greatly from the information contained in reference (65).

Institute of High Temperatures (IVT) of the USSR Academy of Sciences, was the chairman of the council(66). The existence of such a council and program indicates the importance the Soviet government has attached to coal conversion R&D. However, as we shall see, this support has not yet resulted in successful commercial application of coal conversion technology.

The technologies will be discussed in the same order that Sheyndlin discussed them in a 1981 article on synfuels, namely, coal gasification, coal liquefaction, and the ETKh-175 flash-pyrolysis process(67). (Underground coal gasification is discussed in chapter 7.)

History of Soviet Efforts

During the early five-year plan periods efforts were made to gasify lignites (from near Moscow and Chelyabinsk), anthracites, peat, and oil shale. These efforts were aimed at developing local fuel reserves as an alternative to existing fuels being brought from distant points(68).

As a result of these efforts, by 1958 there reportedly were 350 surface coal gasification stations in operation in the Soviet Union producing 35 billion m^3 of low-sulfur gas per year(69). In addition to these efforts which seem to have been oriented to the production of low-BTU gas for local use, technology for the production of high-BTU gas from Moscow Basin lignite was commercialized in the 1950s. One such plant—located at Shchekino (south of Moscow)—produced synthetic gas from lignite for household use that had a high enough heat content (4,500 kcal/m^3) to justify pipeline shipment to Moscow, 200 km away(70).

But because of the discovery and rapid development of inexpensive natural gas in the early 1960s, many coal gasification facilities were dismantled, and eventually most coal gasification efforts were suspended(69). Coal gasification R&D fell to a relatively low level but has begun to recover in the past few years because of growing Soviet difficulties in maintaining growth in crude oil output.

Current Efforts

At present, there appear to be five primary centers of coal gasification R&D. The recently formed Ministry of Fertilizer Production has been given the role of program manager for coal gasification. The other four centers are found in the USSR Ministry of the Coal Industry, the USSR Ministry of Power and Electrification, the USSR Ministry of Higher and Specialized Secondary Education, and the academy system.

The Ministry for the Production of Mineral Fertilizers. The lead organization for work on coal gasification is the relatively new Ministry for the Production of Mineral Fertilizers, which has been assigned the task of producing synthesis gas, which, in turn, is to be transformed into motor fuel. (It is not clear if this effort is to result in feedstocks for production of chemicals as well.) This ministry's efforts will be pursued by the "Azot"* Production Association (PO) in Shchekino, the State Scientific Research and Design Institute for the Nitrogen Industry and Products of Organic Synthesis (GIAP), and a number of research elements at academy institutes and higher schools. A Shchekino gasification plant controlled by the "Azot" association is to be rebuilt, and a pilot plant is to be constructed at the Shatura Branch of the USSR Academy's Institute of High Temperatures.(67)**

The details of this effort are not clear, but we have constructed the following picture from fragmentary evidence. In 1956 R. S. Palta described experimental gasification activities carried out at the Shchekino Gas Works. Various types of brown coal and peat were gasified in a steam-oxygen blast at about 20 atmospheres on a fixed bed (i.e., in a Lurgi-type gasifier). The resulting gas had a calorific value of 4,200 kcal/nm^3*** and was described as suitable for use as a household gas or as a synthesis gas. However, Palta had doubts about the economics of the process when applied to Moscow lignite because of the cost of this coal and suggested that the process was most applicable to regions that were not likely to be supplied with natural gas(71).

According to Altshuler's 1976 book, the Shchekino Gas Works supplied gas to Moscow for several years. However, with the advent of inexpensive natural gas, coal gasification was discontinued and the plant was turned into a chemical enterprise(68). It seems likely that this plant was placed under the control of the "Azot" PO and now is to be reconstructed for service as a coal gasification installation.

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*"Nitrogen" in Russian.

**Shchekino is about 200 km south of Moscow, while Shatura is about 125 km east of Moscow. The Shchekino plant referred to is probably the old gasification plant just mentioned.

***Standard cubic meters.

GIAP is not well represented in the recent literature on coal gasification (which is dominated by IGI articles), but it was subordinate to the USSR Ministry of the Chemical Industry (which gave birth to the Ministry for the Production of Mineral Fertilizers) and has some past experience with coal gasification. On the latter point, Altshuler provides schematic diagrams and operating results for GIAP efforts carried out in the 1950s, including experimental gasification in a fluidized bed (15–20 m.t./day of coal). One unit developed by GIAP reportedly produced a synthesis gas suitable for the production of ammonia(68).

According to a 1979 article by IGI researchers, the Severodonetsk Branch of GIAP is working on the problem of producing methanol from coal, which, in turn, could serve as a reserve fuel for electric power stations; as a base fuel for gas turbines, small boilers, and heat-and-power plants (TETS); and as a motor fuel for auto transport (alone or in combination with gasoline). Assuming that Kansk-Achinsk lignite from Irsha-Borodino is gasified in a fluidized-bed gasifier under 10 atm of pressure, the authors demonstrate that methanol produced by this route will be about 10 percent more expensive than methanol produced from natural gas(72).

Evidently, the old gasification plant at Shchekino is to be the focal point for an effort by the Ministry for the Production of Mineral Fertilizers to investigate technological and economic aspects of the production of methanol (and possibly chemicals) via coal gasification.

The USSR Ministry of the Coal Industry. In terms of degree of experience and depth of staff, Minugleprom's IGI would appear to be the most experienced performer of coal gasification R&D in the Soviet Union. IGI's most notable effort has come in the development and refining of a pressurized fluidized-bed process for gasifying high-sulfur coal(69, 73).

Soviet experimental work on gasification of coal in a fluidized bed dates back at least to the 1930s(74). However, the early process had a number of shortcomings, including significant losses of fuel in the exiting gas, unstable aerodynamics in the fluidized bed, frequent slag formation, and low chemical reactivity(75).

In 1958 Sechenov and Altshuler of IGI reported on efforts to reduce these problems by raising the pressure in the process beyond atmospheric levels(75). (At that time IGI was subordinate to the USSR Academy of Sciences.) The research described in 1958 did not employ coal in the fluidized bed, but in 1959 the same authors reported on efforts to gasify fine-grain solid fuels in a laboratory model of a pressurized fluidized bed. Successful experiments were carried out with pressures of 0.1–0.3, 3, 10, and 15 atmospheres, and steam-air and steam-oxygen blasts(76). In 1962 Sechenov and Altshuler reported on laboratory efforts to gasify Kansk-Achinsk lignite (from the Irsha-Borodino surface mine)(77). As a result of these experiments—which employed steam-air and steam-oxygen blasts and pressures of up to 20 atm—the authors demonstrated that it was possible to produce a power fuel with a heat content of 1,200 kcal/nm^3 and high-caloric gas with a heat content of approximately 3,800 kcal/nm^3(73).

In spite of these early successes there appears to have been limited follow-up. A 1967 publication by Sechenov and Altshuler says little more than the one in 1962(78), while a 1971 article by Sechenov (published posthumously) focused on application of the process to high-sulfur coal and directs the reader to articles published in 1962 and 1963 for details on the apparatus (which still produced only 6 nm^3 per hour)(73).

In Sechenov's 1971 article, he describes a process in which high-sulfur coals from the Novomoskovskiy region of the western Donbass were reduced to 1.0–1.6 mm particles that were subjected to a steam-air blast at 900–1,000°C and 10 atmospheres of pressure(73). With a steam consumption rate of 0.4–0.6 kg/kg of working fuel, it was possible to produce power gas with a heat of combustion of 1,100-1,220 kcal/nm^3. Provision is made for hot cleaning of the gas to remove hydrogen sulfide. A. A. Krichko, the director of IGI, has described the process as analogous to gasification processes worked out by Westinghouse in the United States and by Saarberg-Hölter in West Germany(69).

In late 1982 Krichko reported that IGI and the Central Scientific Research and Project Design Boiler and Turbine Institute imeni Polzunov (TSKTI) in Leningrad had developed a coal gasification process incorporating a fluidized-bed of fine-grained coal at a pressure of about 20 atm. The steam-gas cycle uses pure gas with a temperature of 500–700°C. A pilot plant is to be built during the 11th (1981–85) and 12th (1986–90) Five-Year Plans(79).

Krichko pointed out a number of advantages of the IGI fluidized-bed coal gasification process in a 1978 article(80). He argued that the process is highly productive (3 to 3.5 times more intensive than contemporary Lurgi gas generators); is characterized by lower fuel losses (2 to 2.5 times lower than with Winkler gas generators); conserves the physical heat of the gas, thereby raising the total energy efficiency of the process; employs a simpler method of removing hydrogen sulfide from the products of gasification than cleaning of stack gases; and permits a high degree of cleaning of gasification products thereby enabling them to be employed in gas turbines(80). (In mid-1977 Krichko indicated that the IGI process was in the experimental testing stage[69].)

The USSR Ministry of Power and Electrification. A third center for contemporary study of coal gasification is Minenergo's ENIN. ENIN has developed a process for thermal coking of coal in a fluidized bed. Although this process is primarily designed as a means of upgrading lignite to improve its transportability, the process also yields substantial amounts of gas. The process was tested by ENIN and the Eastern Scientific Research Coal Institute in Sverdlovsk from 1969 to 1975 using a 250-m.t./day pilot plant(81). Although the tests appear to have been successful, there is no evidence of an effort to commercialize this technology apart from the semi-coking process. (A fixed-bed flash pyrolysis technology also has been developed by ENIN. The technology will be tested in a demonstration installation at Krasnoyarsk. See below under "Coal Enrichment" for details.)

USSR Ministry of Higher and Specialized Secondary Education (MVSSO SSSR). Efforts within MVSSO SSSR are largely fundamental or applied research into the chemical principles of coal gasification. The leading university-level facility in this area is the Moscow Chemical Technological Institute imeni Mendeleyev (MKhTI). MKhTI's leading researcher in coal gasification appears to be S. D. Fedoseyev, who has published numerous articles on the topic since the 1960s. A collection of some forty articles on solid-fuel processing published by MKhTI in 1976 included eleven articles by Fedoseyev dealing with various related topics(82).

Coal gasification research also is being conducted by the Tomsk Polytechnical Institute, MVSSO RSFSR, which is continuing work begun by IGI on synthesis of $CO + H_2$ mixtures(83).

Academy Efforts. Coal gasification research within the academy

Table 10 Key Facilities and Persons in Coal Gasification R&D

Institute of Fossil Fuels, Minugleprom, Moscow
V. S. Altshuler
G. P. Sechenov
A. A. Krichko
I. P. Krapchin
V. V. Lebedev
I. I. Chernenkov

"Azot" Production Association, Ministry of Fertilizer Production, Shchekino

State Scientific Research and Project Institute of the Nitrogen Industry and Products of Organic Synthesis (GIAP), Ministry of Fertilizer Production

State Scientific Research Power Engineering Institute imeni Krzhizhanovskiy (ENIN), Minenergo, Moscow

Eastern Scientific Research Coal Institute, Ministry of Ferrous Metallurgy, Sverdlovsk

Central Scientific Research and Project Design Boiler and Turbine Institute imeni Polzunov, Leningrad

State Institute for Designing Underground Mines, Open-Cast Mines, and Preparation Plants, Minugleprom

Moscow Chemical-Technological Institute imeni Mendeleyev, MVSSO SSSR
S. D. Fedoseyev

Institute of Organic Chemistry imeni Zelinskiy, USSR Academy of Sciences, Moscow

Institute of Petrochemical Synthesis imeni Topchiyev, USSR Academy of Sciences, Moscow

Institute of Catalysis, Siberian Division, USSR Academy of Sciences, Novosibirsk

Tomsk Polytechnical Institute, MVSSO RSFSR

system is being conducted by the Institute of Organic Chemistry imeni Zelinskiy and the Institute of Petrochemical Synthesis imeni Topchiyev, both of the USSR Academy, and by the Institute of Catalysis of the USSR Academy's Siberian Division. Research in these institutes appears to be directed toward development of new catalytic systems and production of chemical products from coal, including motor fuel(83).

A list of key facilities and personalities known to be engaged in coal gasification R&D is given in table 10.

The Economics of Coal Gasification

In view of IGI's continuing discussions of the economics of the coal gasification technologies that IGI, ENIN, and GIAP are considering, the debate on the economics of coal gasification seems likely to continue. Gasification of coal for local household use or for pipeline transport does not appear to be economical. The debate now seems likely to focus on the merits of gasification as a route to producing an "energy carrier," such as methanol, that can be transported economically out of Siberia and used as a fuel or as a chemical feedstock in the European USSR.

Although the Soviets have not, as far as we know, published good estimates of the costs of gasifying coal, it is evident that they have begun to rank their coal deposits in terms of their economic suitability for gasification. Kansk-Achinsk coal is probably one of the most suitable for gasification and has received considerable attention in recent years. One source reports that the product of gasification of Kansk-Achinsk coal is estimated to be only one-third as costly per ton of standard fuel as products from the gasification of Donets coal(84). Moscow Basin coal also is considered to be especially suitable for gasification because of the savings on pollution controls that would be required if this coal were burned directly. Ekibastuz coal also is considered a good candidate for gasification because it has high ash content(85).

At present, however, no Soviet coal gasification products can compete with natural gas. Unless natural gas costs rise, or it proves impossible to produce natural gas quickly enough to satisfy national needs for energy, it will not be economically rational for the Soviets to develop coal gasification on a large scale. But political considerations appear to be looming large and may yield an outcome other than the one that seems economically optimal.

The Politics of Coal Gasification

The current Soviet effort in gasification of coal appears to be somewhat confused and appears to reflect the influence of politics. We consider the logical technical leader of Soviet R&D efforts to be the USSR Coal Ministry's IGI, which clearly is the center of past experience in coal gasification R&D and which has most of the Soviet personnel who are knowledgeable about this technology. A. A. Krichko of IGI would seem to be the logical leader of Soviet efforts to gasify or liquefy coal, at least while the technology is in the R&D phase. Instead, the leadership position has been given to A. Ye. Sheyndlin. Sheyndlin is a prominent Academy scientist and able administrator of research, but his expertise is in MHD and nuclear power, not coal.

In part, this decision of the Soviet leadership to select Sheyndlin rather than Krichko appears to reflect annoyance with the USSR Ministry of the Coal Industry, which, given its inability to keep coal production from slipping since 1978, perhaps is not seen as competent to take the lead. By contrast, the USSR Academy and Sheyndlin have been successful and are in favor today. Sheyndlin may also be seen as stronger in political circles and as a more competent bargainer in budget fights. In addition, the choice of Sheyndlin may have been dictated by a perceived need to find a neutral party to weigh the merits of competing technologies. IGI and ENIN are strong advocates of their own technologies and perhaps cannot be trusted to judge them impartially.

The organizational approach adopted seems to place increased emphasis on the prospective users of gasification technology (e.g., the fertilizer industry) and reduced emphasis on the domestic suppliers of raw materials (e.g., coal) or technology for gasification. As further evidence of this, it is worth noting that the Soviet Union is reported to be negotiating with West Germany to obtain German technology for gasification of coal as a step in the production of methanol from Kansk-Achinsk coal(86). In this process of changing emphasis, IGI and its parent, the USSR Ministry of the Coal Industry, would appear to be losers, while the new Ministry for the Production of Mineral Fertilizers must be classed as a winner. The status of ENIN and the Ministry of Power and Electrification in this competition is not clear.

There is a personal side to this struggle. A September 1981 report on negotiations between the USSR and West Germany for acquisition of German gasification technology indicates that the chief Soviet personality in the talks was Deputy Prime Minister Leonid A. Kostandov(86). Before assuming this post in November 1980 Kostandov was the head of the USSR Ministry of the Chemical Industry, which, in 1981, gave birth to the new fertilizer ministry(86, 87, 88).

Kostandov's ascension to deputy prime minister probably was an important explanatory factor in the emergence of the fertilizer ministry as the lead organization in Soviet coal gasification efforts. If nothing else, it can be assumed that Kostandov knew the industry and understood its capabilities to benefit from this technology. And, since his former ministry was not an important source of Soviet R&D or new technology in gasification, the decision to look abroad for technology was no reflection on his past work.

Evaluation

Although the Soviets have three efforts under way to promote coal gasification, we would not be surprised if the program is scaled back at some point in the future. The decision to pursue coal gasification does not appear to be built on firm economic and political foundations and may well falter. The technical literature reflects serious doubts about the economics of gas from coal as a competitor with natural gas, and there are other ways to exploit the coals of the east that may prove more fruitful (e.g., the coal-by-wire option discussed earlier). In addition, the Soviets have yet to regain the level of coal production achieved in 1978. Without more coal, the gasification issue may be moot.

On the political side, the passing of Brezhnev from the scene could well reduce the influence of Kostandov* and dim prospects for methanol from coal. Eric Jones has concluded that there is not good agreement in the leadership about the role that coal should play(89).

In conclusion, the USSR is devoting serious attention to the possibility of gasification of coal, especially as a means of producing methanol. But, unless the economics of this route are demonstrated to be on firmer ground, we doubt that the efforts will be sustained.

Coal Liquefaction (Option 6)

Introduction

Soviet motives for wanting to convert part of their coal and oil shale into liquid or gaseous products, rather than utilizing all of these fuels in solid form, are not unlike Western motives. A 1978 discussion by A. A. Krichko et al. of IGI noted that (1) solid fuels are less convenient to utilize than are gaseous or liquid fuels, (2) there are more environmental problems with solid fuels in general, and (3) some present consumers of liquid or gaseous fuels cannot replace these products with solid fuels(90). Therefore, the conversion of solid fuels into gaseous or liquid products is seen as a means of substituting away from increasingly scarce and costly crude oil and natural gas, while still enjoying the benefits of using fuels that have a gaseous or liquid form. In the process of converting solid fuels into liquids or gases one can at the same time remove some of the most environmentally damaging ingredients of the solid fuel (e.g., sulfur).

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*Since the above was written both Kostandov and Brezhnev have died.

Description of the Technology

The leading Soviet facility for coal liquefaction R&D is IGI, which has been pursuing such work actively since at least 1968. IGI's director, A. A. Krichko, has had a distinguished career in this area of research and is a leading advocate of coal liquefaction. IGI is being assisted in this work by the "Grozgiproneftekhim" Institute and by the All-Union Scientific Research Institute of Chemical Machine Building. Research on liquefaction of Kansk-Achinsk coal also is being conducted in cooperation with the German Democratic Republic and Poland(79).

The USSR is a late starter in coal liquefaction research and currently has a firmer grasp of the theoretical principles than it has of the engineering concepts required even to build pilot-scale liquefaction plants. Currently, IGI has a bench-scale unit in operation that produces three liters of synfuel per day(91). A pilot plant is under construction south of Moscow at the "Belkovskaya" mine and was to be in operation in 1983. A second plant in Kansk-Achinsk was to be finished in 1985(79). No other coal liquefaction process is being developed that could compete with the IGI process.

The recent announcement that the USSR is expected to begin negotiations with the West Germans for the construction of a commercial liquefaction plant in the Kansk-Achinsk region strongly suggests that the Soviet government does not consider indigenous success in this area as likely within any desirable time frame(92). This may be due either to the perceived inadequacy of the IGI process as a basis for commercial-scale installations or to pessimism over the competence of the Soviet engineering and construction sector to build such a plant.

The hydrogenation process developed by IGI is similar to the Exxon Donor Solvent (EDS) process and the H-coal liquefaction process, but where the Western processes use coal-derived solvents, the IGI process uses petroleum-derived solvents. The process yields up to 65 percent low-sulfur boiler fuel, up to 25 percent automotive fuel, and 2–3 percent volatile phenols. A 90–93 percent efficiency rate is claimed(93). The 1968 author's certificate describing the process gave the process parameters as 400–450°C, and exposure of the coal–crude oil mixture to hydrogen at a pressure of 50–150 atmospheres(94). However, the pressure parameter generally has been reported as 100 atmospheres, while various temperatures have been reported, ranging from 425°C in a 1971 research paper(95) to 380–390°C in a May 1981 report(96). By contrast, the EDS and H-coal process parameters range from 100 to 200 atmospheres and from 400 to 460°C, depending on the products to be produced.

According to Krichko et al., the utilization of a relatively low pressure parameter (i.e., 100 atmospheres) is made possible by the use, as an active catalyst, of a mixture of cobalt, aluminum, molybdenum, and (possibly) iron compounds that facilitate the activation of molecular hydrogen and the destruction of coal materials, plus the use of a series of active organic additives (0.2–5 percent) that prevent the formation of thickening agents (*produktov uplotneniya*) during liquefaction of the coal. IGI has worked out a regeneration process that makes it possible to recover 95–97 percent of the molybdenum(90).

Some might consider the use of petroleum-derived solvents to be inappropriate or at least curious, given the overriding purpose of replacing petroleum with products of coal liquefaction. Krichko has addressed this point in several articles (perhaps in response to domestic criticisms of this feature of the IGI hydrogenation process). In a 1971 article he noted that high-pressure hydrogenation of coal would require a 5–6 percent consumption of gaseous hydrogen to achieve a 95–97 percent transformation of coal, whereas the IGI process permitted the consumption of hydrogen to be cut to 1.5–2.0 percent because of the role of crude oil as a hydrogen donor in the process(95). In a 1978 article Krichko et al. noted that at present the cost of hydrogen embodied in petroleum is much lower than is the cost of gaseous hydrogen and hence that the use of crude oil products as hydrogen donors is appropriate at this time. While the authors recognized that rising petroleum costs ultimately will make the use of other donors more advantageous, they argued that the use of petroleum in this capacity may remain economically rational for a comparatively long time—at least until the exhaustion of petroleum reserves becomes a "real factor"(90).

An interesting feature of the IGI process is the role of sulfur in the transformation. Crude oil containing sulfur can be employed in the process because very little of the sulfur ends up in the liquid products obtained(95). Furthermore, the 1968 authors' certificate describing the process specified "sulfurous" or "highly sulfurous" crude oil(94). In fact, sulfur appears to play a beneficial role by increasing the yield of liquid products and decreasing the formation of gaseous methane hydrocarbons. Thus, when crude oil fractions containing 1.6 percent sulfur rather than 3.4 percent sulfur are employed the degree of transformation of the coal into liquid products declines by 10–12 percent(95).

Over the past decade, scientific papers on the IGI hydrogenation process have dealt with experiments on several types of coal. A 1971 article (95) discussed the use of Kuzbass coal, while a 1972 article (97) dealt with Cheremkhovo and Gramoteino coals. The "ST-5" pilot plant is to employ Moscow Basin brown coal, while subsequent test facilities are to be based on Kansk-Achinsk lignites. Current research appears to be focused on Kansk-Achinsk coals, although one recent article indicated research on liquefaction of coals found in or near Mongolia(98).

Pilot Plants

Pilot plant testing of the IGI hydrogenation process was to begin before 1980, with industrial application to follow by 1990(82, 83). However, the Soviets have fallen behind schedule in these efforts. The first pilot plant, called the "ST-5" (because originally it was to process five metric tons of coal per day), experienced some delays but was scheduled to come on stream in late 1983(67). This installation is located at the "Belkovskaya" mine in Tula Oblast and will process 7-10 m.t. of lignite from the Moscow Basin per day, producing at most 2.5 m.t. of motor fuel per day.

Perhaps because of delays in the construction of the ST-5, the schedule for scaling up this technology has become very compressed. The next stage in the development of the IGI hydrogenation process is to be the construction of a plant capable of producing 20 m.t. of fuel per day. This unit, to be called the "ST-75," is intended for the "Berezovskiy-1" surface mine in the Kansk-Achinsk Basin and originally was scheduled to be completed in 1984,* but the schedule was slipped to 1985(67, 79). If these two installations were successful, a larger plant–the "ST-500"–was to be built after 1985(66).** Soviet negotiations with West Germany for the purchase of a coal liquefation installation for KATEK suggest that the ST-75 and ST-500 projects have been scrapped.

Supporting R&D

Work on the basic IGI hydrogenation process has been supported by a series of parallel studies that undoubtedly have helped IGI researchers to perfect the process and gain a better understanding of its commercial possibilities. In 1972 Krichko and others published an article on hydropurification of mixtures of distillate fractions from coal and crude oil(97). This research—which was concerned with the removal of sulfur-, nitrogen-, oxygen-, and unsaturated compounds—was carried out with 40:60 and 50:50 mixtures of coal and crude oil. Cheremkhovo and Gramoteino coals were employed. A 1975 article by some of the same authors presents a method for mathematical modeling of the same hydropurification process, illustrating the approach with a 40:60 mixture of distillates from Cheremkhovo coal and Arlanskiy crude oil(100).

Parallel studies also have been conducted on the problem of hydrocracking of distillates resulting from liquid-phase hydrogenation of coal. A 1973 article by Krichko and other IGI scientists reports the results of hydrocracking of a distillate from an unspecified coal-oil mixture(101). The fraction employed in the experiments had a boiling temperature of 180–320°C, while a zeolite containing 3.5 percent MoO_3 was employed as a catalyst. A single pass through the hydrocracking unit transformed 52.6 percent of the feedstock into gasoline (having a boiling temperature of up to 180°C), while multiple passes raised the gasoline yield to 89.6 percent. As an alternative to multiple passes, the residue (having a boiling point above 180°C) can be employed as a component of low-sulfur winter diesel fuel. A 1976 article by IGI researchers presents the results of mathematical modeling efforts using the same raw material catalyst and experimental methods and aimed at maximizing the yield of gasoline, subject to certain technological constraints(102).

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*The chief builders of the ST-5 and the ST-75 are the USSR ministries of the coal, the petrochemical and petroleum refining, and the chemical machine building industries(99).

**The "ST-500" is being undertaken as a CMEA project. Technical documentation for the installation was to be developed by the end of the Eleventh Five-Year Plan(62).

Facilities and Personalities

IGI is the primary R&D facility in this field. Its director, A. A. Krichko, is a widely published advocate of coal liquefation. IGI and other key coal liquefaction facilities and persons are listed in table 11.

Table 11 Key Coal Liquefaction R&D Facilities and Persons

Scientific Council for Obtaining Synthetic Fuels, GKNT

Institute of Fossil Fuels, Minugleprom, Moscow

- A. A. Krichko
- A. A. Galkina
- T. A. Titova
- V. V. Zamanov
- S. V. Makaryev
- V. P. Davydov

Groznyy State Institute for Designing Enterprises of the Petroleum Refining and Petrochemical Industry (Grozgiproneftekhim)

All-Union Scientific Research and Project Design Institute of Petroleum Machine Building

All-Union Scientific Research Institute of Chemical Machine Building

Institute of Physical Organic Chemistry and Coal Chemistry, Ukrainian Academy of Sciences

Kuzbass Polytechnical Institute, MVSSO RSFSR, Kemerovo

Irkutsk Polytechnical Institute, MVSSO RSFSR

Institute of High Temperatures, AN SSSR, Moscow

Institute of Hydrolysis, SO AN SSSR, Novosibirsk

Institute of Chemistry and Chemical Technology, SO AN SSSR, Krasnoyarsk

It is probable that several dozen other institutes are working on the coal liquefaction program.

The Economics of Coal Liquefaction

The production of coal liquefaction products is not economically rational at present and will not be until petroleum extraction costs rise further (and/or coal liquefaction costs fall). As an example, it was estimated in mid-1981 that gasoline produced from coal by the hydrogeneration process would be three to four times more costly than gasoline produced from crude oil(96).

IGI specialists believe that it is only a matter of time until rising oil extraction costs make liquefaction economical. Given IGI's assumptions on the cost of extracting oil from Western Siberian fields, the total cost of extracting and transporting crude oil is twice as high as the same cost for coal; but since liquefaction is four times as expensive as petroleum refining to obtain home heating oil, coal liquefaction products would still be 10 to 15 percent more costly than petroleum products. However, should the extraction cost of crude oil exceed 70 rubles/ton, coal liquefaction would become more economical than refining crude oil(80). IGI argues that this will be the case sometime after 1990. Finally, IGI's Krichko has argued that coal liquefaction would be more economical than processing of oil shale or tar sands(93).

Enrichment of Kansk-Achinsk Lignite (Option 7)

Introduction

A clean fuel with a high carbon content can be obtained from low-grade coals through carbonization or destructive distillation (decomposition of coal by heat in the absence of oxygen)(103). Carbonization processes result in some form of solid, coherent residue (coke, semi-coke) as well as liquid products (benzole, oils, and tar) and gaseous products. The mix of products and their chemical structures depend on the nature of the coal and the conditions of carbonization (103). The partial carbonization of Kansk-Achinsk lignite is seen as a solution to the problem of its poor transportability and currently is being seen also as a means of obtaining a clean burning fuel for industrial and residential use. Since transport of Kansk-Achinsk lignite to the Center of the European USSR may become necessary in coming decades, considerable effort has been expended by ENIN and IGI to develop technologies to upgrade this coal.

ENIN has developed four processes that essentially result in a semi-coke (or char), with gaseous and liquid by-products. IGI has developed a "thermocoal" (dried coal) process that enriches the coal, largely by removing moisture, but does not yield by-products. During the early 1970s there was a substantial rivalry between ENIN and IGI. Each institute aimed at having Party and government officials incorporate its process into plans for development of KATEK. IGI boasted lower per unit costs for its process, while ENIN boasted a more useful coal product and more valuable by-products from its process. In addition, ENIN's semi-coke was considered a better form of coal for slurry pipeline transport than thermocoal. Since thermocoal is largely a cleaned, dry coal, it was argued that it made little economic sense to re-wet the coal in a slurry. IGI countered by proposing to tar the thermocoal prior to transport.

ENIN Processes

ENIN has developed three pyrolysis processes known as (1) the fixed-bed, combined heat-carrier, flash pyrolysis process; (2) the gaseous heat-carrier agent process; and (3) the three-stage, heat-transfer agent process. A fourth ENIN process, known as thermal-contact coking, also has been developed.

Fixed-Bed, Combined Heat-Transfer Agent Process. ENIN has developed a flash-pyrolysis technology for producing char or semi-coke (thermal value of 27.2-29.3 MJ/kg), tar, and fuel gas (about 21 MJ/kg) from lignites, primarily those of the Kansk-Achinsk Basin. This technology is being tested in the ETKh-175 (expansion unknown) semi-coking facility being built at the Kansk-Achinsk Basin. It is said to be economical because of its high rate of heating. (The rate of heating is said to be 1,000,000°C/sec in contrast to 1–10°C/sec with ordinary pyrolysis[104].) (The inspiration for this multiproduct process may be the South African concept known as "Coalcom," an acronym for coal, coke, oil, and megawatts, for upgrading low-grade coals. Coalcom, like the ETKh-175, is based on existing technology[105].) A diagram of the ETKh-175 process is shown in figure 7.

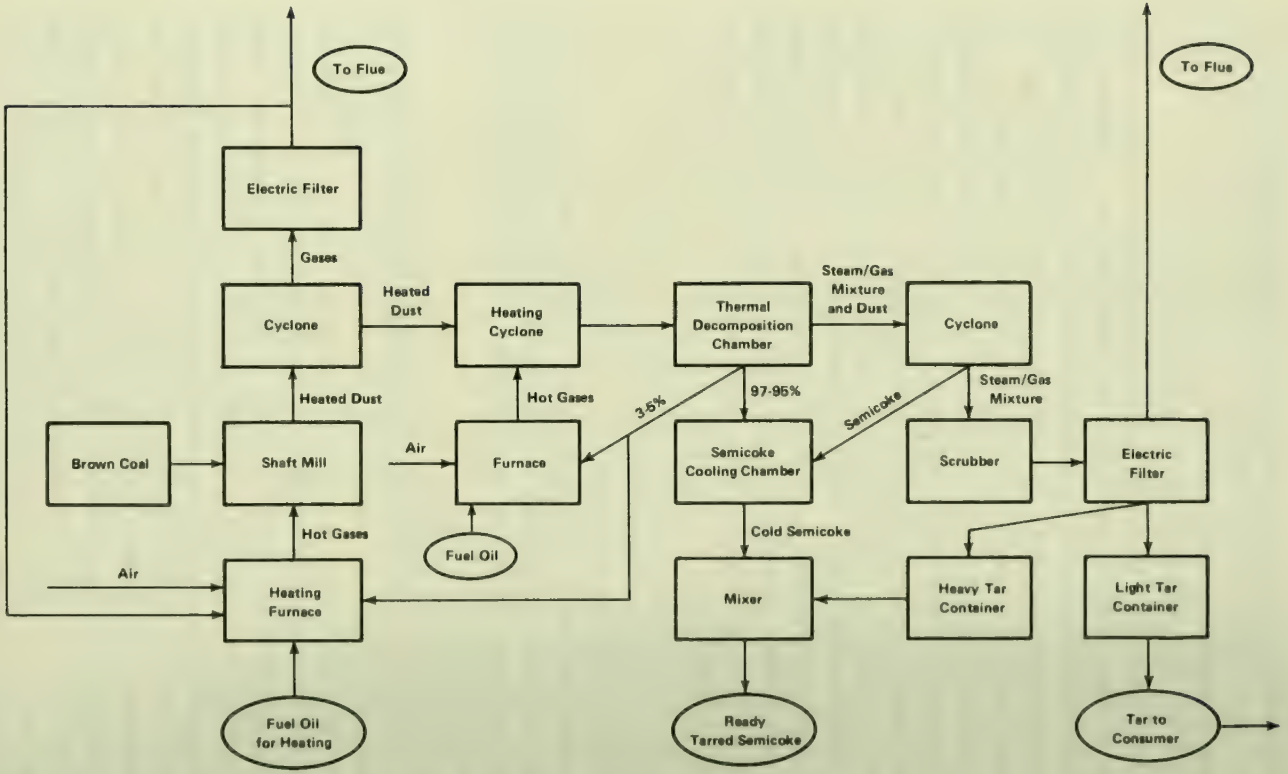

Figure 7 Schematic Diagram of the ETKh-175 (figure credit: Soviet Export)

The ETKh-175 is designed to produce 175 m.t. of semi-coke per hour with an annual output of 300,000 m.t. of semi-coke; 120 million m^3 of fuel gas; up to 100,000 m.t. of tar that can yield 50,000 m.t. of boiler fuel; 15,000 m.t. of gasoline and 20,000 m.t. of bitumen plus several thousand m.t. of other useful chemicals(104).

Development History of the ETKh-175. In 1957 a combined heat-transfer agent pyrolysis installation with a capacity to process four tons of run-of-mine coal per hour was set up at the Kalinin Heat and Power Station (TETS) No. 2. The Unit processed Moscow Basin coal until 1963–64 when Kansk-Achinsk lignite was substituted because of the rising cost of Moscow coal. In 1965 a 6 m.t./hr. unit was built at the "Sibelektrostal" Steel Plant(28). Construction of the ETKh-175 pyrolysis installation was begun by Teploelektroproyekt of Minenergo and other organizations at Krasnoyarsk TETS No. 2 in 1975(28). But construction came to a halt in late 1978 because of the failure of suppliers to produce or deliver needed equipment(111). In 1981 it was reported that the unit was scheduled to be completed by the end of 1981, but by the beginning of 1983 the ETKh-175 was still unfinished(40).

Most of the Soviet literature has stressed the role of the ENIN process in producing a solid fuel with a high thermal value per unit of weight. One article notes, for example, that the char obtained from the process could be briquetted and transported from Kansk-Achinsk to the Center, yielding a solid fuel that is 20 to 25 percent cheaper than Tyumen gas or run-of-mine Kuzbass coal(107). However, an article by Academician A. Ye. Sheyndlin pointed out the potential value of the tar by-products of the process (comprising up to 15 percent of the total) as feedstocks for the production of motor fuel and chemicals(67). Semicoke briquettes could be used in metallurgy for sintering ores and in making partially metallized pellets(109).

Gaseous Heat-Transfer Agent Process. ENIN also has developed a pyrolysis process using a single gaseous heat-transfer agent that is similar to the above process except that it has no solid heat-transfer agent loop. The coal is ground and dried in a shaft mill and then heated to 300–400°C by an inert (to oxygen) gaseous heat carrier(106).

Three-Stage Heat Transfer Agent Process. In this process, dried, crushed coal is fed into a heating retort, then into an intermediate heating retort, and finally into the pyrolysis reactor. The char then is passed through a cooler(106).

Thermal-Contact Coking. Thermal-contact coking in a fluidized bed was tested by ENIN and the Eastern Scientific Research Coal Institute (VNIUI), Sverdlovsk, from 1969 to 1975 using a 250-m.t./day experimental unit(110). The process yields char, fuel gas, tar, and steam(81). It is reported that ENIN intended, during the period 1976–80, to design thermal-contact coking units (TKKU) with outputs of 300 and 900 m.t./hr (the TKKU-300 and TKKU-900, respectively)(110).

The TKKU process has not been thoroughly described, but because its essential features were borrowed from a Soviet petroleum refining process, its characteristics can be guessed from study of the petroleum process. The TKKU process probably consists of the heating of coal and coke in a fluidized bed. In the petroleum refining process, coke is cycled as a solid heat-transfer agent between the reactor and the coke heater. The coke is heated by its partial combustion in the coke heater and passed to the reactor where atomized petroleum is injected into a fluidized bed of coke. The fuel is evaporated and coked on the surface of the heat-transfer agent(81).

Current Status of the ENIN Technologies. After a flurry of activity through the mid-1970s ENIN's activity in this area, if we can judge by the decline in published articles on this topic, seems to have fallen. Construction of the ETKh-175 was still in progress in early 1983, five years after its scheduled completion date. The project has suffered from the same problems confronting many Soviet projects that require interagency coordination but do not receive strong, interested supervision by the top levels of the Party or government. The design documentation has been inadequate for the builder's needs, custom-designed equipment and parts have been difficult to obtain, and the best workers have periodically been pulled off to other, more important, construction sites. A general shortage of labor also has existed at the site(108).

The ENIN process thus appears to be a long way from commercial application. Problems related to scaling up the ETKh-175 still exist. No dates have been mentioned, as far as we know, for the start of construction on larger semi-coking facilities. In addition, there still are unsolved problems connected with the conversion of the process resins into motor fuel and with the use of the semi-coke itself.

The IGI Process

The IGI "thermocoal" process yields a dried, transportable coal with a caloric value of 6,200 kcal/kg. The dried coal can be coated with a tar by-product of the process to prevent self-ignition of the coal during transport or in preparation for slurry pipeline transport.

Thermocoal is produced in a three-stage process that involves heating the coal to 450–550°C in a turbulent stream of gas(112, 113). Heat for moisture removal and coal heating is obtained by combustion of volatiles driven out of the coal during the process(113). The process, which does not appear to incorporate much, if any, novel technology, was tested at the Kumysh Experimental Home Fuel Plant using a 312-m.t/hr. unit and at IGI(114). IGI, the Giproshakht Institute in Leningrad, and the Vostsibgiproshakht Institute (location unknown) are developing a pilot plant, known as "Termougol-100," which was planned to be in operation by 1985(62, 115). In the longer term, Sibgiproshakht is proposing to build two thermocoal plants with a combined input of 110 million m.t. of run-of-mine coal per year(62). (Sibgiproshakht had completed the design of a 50 million m.t./year plant in 1975, but no government approval to begin construction has been forthcoming[112].) Technology for coating thermocoal and a water-*mazut* (residual fuel oil) emulsion to prevent self-ignition of the dried coal during transport was developed at the Abashevskaya and Karaganda Coal Preparation plants(114).

A major disadvantage of the IGI process in comparison with ENIN's semi-coke process is the relative lack of valuable by-products. However, IGI claims that thermocoal has several advantages over semi-coke in that thermocoal contains more volatiles, the burning temperature is reduced, nitrogen oxide formation is reduced, and it can be burned in an unground form(114). The thermocoal process is stated to be 89 to 92 percent efficient (roughly comparable to the ENIN process), and the fuel is somewhat cheaper per unit to produce. Development of this technology, however, probably was cut back when the ETKh-175 was selected for Kansk-Achinsk. IGI, in fact, recently has been working with ENIN on the latter's flash-pyrolysis program(116).

Pipeline Transport of Enriched Coal (Option 8)

Introduction

The main directions for development of the USSR economy during the Eleventh Five-Year Plan period called for development of new means of transport, such as slurry and container pipeline transport of coal.* (See appendix B, items 1.e. and 2.a.) GKNT's current goal-oriented program for pipeline transport of coal has three major objectives: (1) construction of the Kuzbass-Novosibirsk slurry pipeline; (2) development of a hydraulic container system by the SKB "Transnefteavtomatika;" and (3) development of a pneumatic container system by SKB "Transprogress"(117). Slurry pipelines are being considered for long-distance coal transport from Siberia to the Urals or European USSR. The current strain on the rail system, coupled with the high steel intensity of rail transport, have made slurry pipelines economically attractive for such purposes. Although slow in introducing slurry transport, the Soviets appear to have geared up for a major development effort in the mid-1980s. Long-distance container pipelines, on the other hand, have as yet attracted little support outside the R&D community since the technology will not be ready for such uses until the 1990s.

Slurry Pipeline Activity

Status of the Technology. Two coal slurry pipelines have been built in the Kuznetsk Basin. One transports 50 mm or smaller lump coal to the Belovo GRES, and the other transports coal to the coal preparation plant of the West Siberian Metallurgical Plant near Novokuznetsk(118). The concentration of coal is only 10 to 15 percent by weight, but the pipe is subjected to substantial abrasion due to the large lump size and the high pumping speed.

Studies of Coal Slurry Pipeline Feasibility. In the second half of the 1970s several ministries and agencies were engaged in a study of U.S. and other Western experience with coal slurry pipelines and a determination of the technical and economic feasibility of coal slurry pipelines in the USSR. These organizations included the ministries of the coal industry, power and electrification, ferrous metallurgy, and construction of oil and gas industry enterprises, as well as the USSR Gosplan.

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*A slurry is a mixture of water (or some other fluid) and an insoluble, pulverized material—coal in this case. The mixture is pumped through a pipeline much in the same manner one would pump crude oil. In container pipeline systems the coal is placed inside cylindrical capsules or containers that are moved through a pipeline by pneumatic or hydraulic pressure.

Economic considerations were taken up by two Gosplan institutes: the All-Union Scientific Research Institute of Comprehensive Fuel and Energy Problems (VNIIKTEP) and the Institute for Complex Transportation Problems (IKTP). In September 1978 Gosplan ordered refinement of feasibility studies for long-distance coal slurry transport of Kuzbass coal to the Urals, the Volga region, and the Center(118).

The Soviets maintain that long-distance slurry transport of coal from the Kuznetsk and Kansk-Achinsk basins is cheaper than rail transport. For two developed variants of transport of Kuznetsk coal, it is claimed that capital expenditures could be 1.8 times less, metal consumption 1.3 times less, labor expenditures for construction 5.5 times less, and labor expenditures for maintenance 12 times less than for rail transport(59).

Ekibastuz coal appears to be too abrasive for coal slurry transport(119), and, at present, pipeline transport of Kansk-Achinsk coal is not considered feasible because of the lack of coal preparation facilities and the lack of suitably powerful slurry pumps(118).

Information on plans for long-distance coal slurry pipeline transport is sketchy. Ye. P. Olofinskiy,* a deputy director of VNIIPI "Transprogress," has indicated that construction of "a few" 1,500 to 2,000-km slurry pipelines with capacities of up to 40 million m.t./yr. was to start before 1985(121). It is rather doubtful that these plans can be acted upon soon. Since existing slurry pipelines are quite short, the technology for a long pipeline has yet to be proven.

Construction Activities. Construction of a 256-km coal slurry pipeline between the "Inskaya" hydraulic mine in the Kuzbass and Novosibirsk TETS No. 5 was to have begun sometime in 1981 and completion of the pipeline was planned for 1985(122). However, preparatory work on the route only began in mid-1982(123). The pipeline will be made of laminated tube from Vyksa (one-half meter in diameter) and will be buried two meters below the surface(122, 123).

*In August 1983 Olofinskiy was identified as being the director of VNIIPIgidrotruboprovod. (The name suggests work on hydraulic pipeline transport.) We have no further information on this organization(120).

(See also the discussion of Arctic pipeline materials in chapter 4.) Originally, the pipeline was to have an annual capacity of 4.3 million m.t. per year, but the capacity has now been lowered to 3 million m.t.(124). The pipeline will be used to study the feasibility of longer-distance pipelines.

Design of the pipeline involved at least VNIIPI "Transprogress," the program leader, UkrNIIGidrougol (Donetsk Department), and Gidrougol.* Construction will be the responsibility of the Ministry of Construction of Oil and Gas Industry Enterprises (Minneftegazstroy), with assistance from the coal, rail, and electric power ministries. VNIIPI "Transprogress" will also handle the manufacturing of non-standard components at a subordinate plant, i.e., within the "Soyuztransprogress" Association(125).

R&D Activities. Little information on the specifics of Soviet coal slurry pipeline transport research is known. Ye. P. Olofinskiy has indicated that a great deal of research has been conducted but has largely been limited to studying "certain processes in hydraulic transport technology" using small-scale experiments(118). Two Soviets writing in 1979 complained that too little attention had been paid to research on the physical and technical properties of pumping water-coal slurries in large-diameter pipes(126). R&D aimed at creating the Kuzbass-Novosibirsk (250-km) coal slurry pipeline arrears to have begun around 1976(118).

An analysis of Soviet literature suggests that Soviet development work over the past six years has been proceeding to the patent stage at a somewhat steady rate of between five and ten patents per year.** The patents have largely been going to developers of component parts, such as valves, fittings, etc., or developers of larger components, such as pumps, feed devices, pipe scrubbers, and hydraulic shock absorbers. A few patents for pipeline systems also have been issued.

According to Olofinskiy, the USSR does not produce pumps with sufficient capacity to support long-haul coal slurry pipelines (i.e., ones running from Kansk-Achinsk or the Kuzbass to the Urals or the Center)(118). Several other problems must be resolved before long-

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*Expansions of the latter two institute acronyms are not known. The term *"gidrougol,"* however, probably refers to hydraulic coal mining wherein a jet of water is used to cut coal off the seam, forming, in the process, a coal-water slurry.

**Patent citations are from *Referativnyy zhurnal: truboprovodnyy transport (Abstracts Journal: Pipeline Transport)*, which may not report all patents issued.

Table 12 Organizations Engaged in R&D on Pipeline Transport of Coal

A. *Slurry Pipelines*

All-Union Scientific Research and Design Institute for Slurry Pipelines (VNIIPIgidrotruboprovod)

All-Union Scientific Research and Project Design Institute of Pipeline Container Systems (VNIIPI "Transprogress"), possibly of the "Soyuztransprogress" Association, Minneftegazstroy, Ramenskoye

Gidrougol

Institute of Complex Transport Problems (IKTP), Moscow

UkrNIIgidrougol, Donetsk

SKB "Transnefteavtomatika," Goskomnefteproduktov

Institute of Mining Mechanics imeni Tsulukidze, AN Georgian SSR

SKB of Hydro-Impulse Technology, SO AN SSSR

PKB(possibly Project Design Bureau) Glavstroymekhanizatsiya, USSR Ministry of Transport Construction

Institute of Geotechnical Mechanics, Ukrainian Academy of Sciences

B. *Container Pipelines*

SKB "Transprogress," Goskomnefteproduktov

SKB"Transnefteavtomatika"

Gruzgidrovodkhoz (Georgian State Institute for Planning of Water Management)

All-Union Scientific Research and Project Design Institute for Pipeline Container Systems (VNIIPI "Transprogress"), Moscow

SKB "Gazstroymashina," Moscow

haul slurry transport becomes feasible. A means must be found for preventing the freeze-up of coal slurry during cold weather and for handling variability in coal characteristics. Special valves and control systems must be developed(127). Pipelines originating in Siberia face the additional problem posed by the slurry's high-volume water requirement(128).

Key Organizations. The "Soyuztransprogress" Association, of which VNIIPI "Transprogress" may be the lead organization, is the center for coordination of all coal slurry pipeline R&D in the USSR. VNIIPI

"Transprogress" has developed a long-term R&D program looking into slurry transport of solid materials(55). (VNIIPI "Transprogress" appears to have been organized in the mid-1970s to undertake R&D on new forms of transport.) Other facilities are listed in table 12.

Container Pipeline R&D.

*Status of the Technology.** The Soviets have gained substantial experience with pneumatic systems and have experimented with hydraulic systems. Their efforts are briefly described below.

Pneumatic Systems. The USSR had five pneumatic container pipeline systems in operation as of the beginning of 1981. The first, the "Lilo-1," began operation around 1971 and carries crushed stone in the region of Shuvaleri in the Georgian SSR. The capacity of the system is 15 m.t. per trip, and its length is 2.2 km(129).

The "Lilo-2," located near Marneul in the Georgian SSR, was in operation by the end of 1980 and is much larger than the "Lilo-1." The "Lilo-2" runs for 17.5 km and can transport 225,000 m.t. of crushed stone per year.

Three container pipeline systems have been built near Moscow. Two, known as the TPK-1 and TPK-3, were put into operation around 1980 and can transport 300,000 m.t. and 4,000,000 m.t. of crushed stone and sand per year, respectively. The TPK-1 is 7 km long, whereas the TPK-3 is only 3 km long. The third Moscow container pipeline system is a short intraplant system at the Moscow "Start" Plant. Its capacity is not known.

Two other systems appear to be in the design stage. The first, known as the KPT-28, is to be 2.4 km in length and have an annual capacity of 300,000 m.t. of crushed stone. The second–the TPK-2–is to be built near the Samotlor oil field. It also has been stated that twelve designs of container pipeline systems have been developed and examined by potential users in recent years.

Hydraulic Systems. Apparently, a number of hydraulic container systems have been conceived and developed to some degree in the USSR. At least two industrial-test hydraulic systems have been built beginning in 1972(133). The systems will be used to study container transport of crude oil and petroleum products using the existing pipeline system. ENIN has also developed a hydraulic container pipeline system. ENIN is proposing the system as a solution to the Kansk-Achinsk lignite transport problem, claiming a capacity of 100 million m.t./yr can be attained(134).

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*The material in this section came from references (130), (131), and (132) unless otherwise indicated.

Recent Activity. Container pipeline development activity has been increasing in recent years, as evidenced by the substantial growth in the number of patents awarded annually. Experimental and operational studies are enabling the Soviets to collect considerable data on container systems that will facilitate the development of new, more powerful systems.

The SKB"Transnefteavtomatika" (possibly subordinate to the State Committee for Supply of Petroleum Products [Goskomnefteproduktov]) is developing a container system for transporting oil and lubricants in elastic bags propelled by a moving fluid. The SKB "Transprogress," also of Goskomnefteproduktov, is leading a program to develop a container system in which trains of wheeled containers are driven distances of up to 100 km by air pressure(119).

The Soviets also are working on the use of nonmetallic pipe for transporting agricultural products. Two test stands have been built near Ramenskoye, near Moscow, for testing pipe, components, and control systems(135).

Prospects for Coal Transport. Although proposals for long-distance container pipeline transport of coal have been made, it seems unlikely that any will be accepted. The government appears to favor slurry pipelines for long-distance coal transport at this time. In fact, little support for container transport of coal is found in the literature. However, further development of the technology could result in a change in official attitudes and increase interest in this novel means of transporting materials.

Key Organizations. About thirty institutes and design bureaus have been identified in the area of capsule pipeline transport.

Much of the R&D is centered in Minneftegazstroy or Goskomnefteproduktov and is coordinated by the Section for Pipeline Container Transport of the Ministry's Scientific-Technical Council(131). Key facilities are shown in table 12 (above).

Evaluation of Coal Options

Until 1960 coal provided more than half of the energy produced in the USSR. The discovery of huge reserves of oil and natural gas since then has resulted in a substantial shift away from coal. However, as in the United States, increases in the cost of crude oil and gas and the prospect of serious depletion of supplies of these two fuels in the next few decades have provided a rationale for a shift back to coal.

However, there are a number of technical, environmental, transport, and economic problems associated with the use of coal. In particular, most of the Soviet Union's supplies of coal are located in the east, far from prospective consumption areas. Although extraction can proceed in these areas by low-cost strip mining, the low ratio of thermal value to weight for these coals makes transport of run-of-mine coal uneconomical. As a result, the Soviets have investigated a number of options for deriving benefits from these eastern coals without shipping raw coal. Proposals include production of a higher-grade solid fuel, liquefaction, gasification, and conversion to electricity with UHV transmission to the Urals or the European USSR.

Although dozens of research and development facilities have been engaged in the exploration of these technological options, the Soviets appear to be making relatively poor progress in putting their research accomplishments to use. Technical literature published in recent years reflects a particular impatience with the directions, levels of effort, and results of past synfuel investigations. Participants at the all-union synthetic fuels conference held in Zvenigorod in 1979 were told that the total volume of research under way did not correspond to the importance of the problem. As a result of the low level of effort and the fragmentation of activity among organizations, it was argued that exploratory efforts aimed at finding new ways of producing synthetic fuels were insufficient and that there was practically no experimental-industrial base for working out and testing new equipment and methods for treating coal(136).

Similar sentiments have been expressed since that conference. In an article published in *Izvestiya* in April 1981 Academician Sheyndlin and Dr. Kalechits of the USSR State Committee for Science and Technology (GKNT) were more charitable about Soviet basic research in this area but were critical of efforts on later stages of the R&D cycle, indicating that while Soviet basic research was on a world level, their engineering experience lagged considerably behind the West. Sheyndlin and Kalechits did not assert that all of the basic technical problems had been solved, observing that more work was needed on the hydrodynamics of heat and mass transfer in a complex multiphase system of coal hydrogenation; optimization of designs for reactors, gas generators, and other apparatus; the selection of materials that are resistant to corrosion and erosion; etc. But they were most critical of applied research and testing activities. The USSR Ministry of the Coal Industry was castigated for wasting several years on the design of a pilot installation, while the USSR Ministry of Power and Electrification was taken to task for delays in the completion of its test installation for high-speed pyrolysis of coal in Krasnoyarsk(66). In June 1981 Sheyndlin again spoke critically of progress in engineering and experimental testing, noting, in particular, that methods of processing motor fuel from resin obtained by the pyrolysis method (the ETKh-175) have not been perfected(67). Possibly in reaction to prior criticism, an Institute of Chemistry and Chemical Technology attached to the SO AN SSSR was created in Krasnoyarsk in 1980 to assist in the selection of coal processing technologies for Kansk-Achinsk coals(137).

Given the Soviet Union's well-know comparative disadvantage in the *implementation* of new technology, we have doubts that the limited number of domestic synfuel technologies under development in the USSR can be commercialized in the near future. Recent negotiations with West Germany about acquisition of German gasification and liquefaction technology may indicate that the Soviet leadership has reached a similar conclusion. In view of the underdevelopment of Soviet technology in this area, as evidenced by a general absence of innovative design solutions, the assimilation of Siberia's coal into the national energy balance at a level sufficient to offset declines in coal production in the European USSR and/or declines in oil production is quite uncertain. Since coal production at the Kansk-Achinsk Basin is being vigorously developed without commensurate solutions to the technical problems of UHV transmission, enrichment for rail transport, or efficient combustion in boilers, one wonders whether the result will not be larger and larger piles of unused coal as production continues to grow beyond local and regional consumption.

Chapter 6 Technologies to Improve the Efficiency of Energy Utilization

Introduction

Like many other countries around the world, the Soviet Union has become very interested in ways to increase the efficiency of energy utilization. In part, this has been a reaction to attractive world prices for crude oil that have made Soviet planners conscious of the high opportunity costs of consuming petroleum at home rather than selling it abroad in return for much-needed foreign exchange. In part, it has been a reaction to threatened imbalances between the supply of and the demand for energy in the Soviet economy. Given the abundance of energy resources, these imbalances may be temporary ones that will last for only a few years, but during that period the imbalances could cause considerable inconvenience to the Soviet economy. Finally, the Soviets recognize the finite nature of fossil fuel supplies and the need to begin thinking about long-run options to replace them. At this time the depletion concern is manifested most clearly in the form of a growing awareness of rising energy production costs as the nearest and most easily exploitable deposits are depleted, and exploration and production shift to increasingly hostile, distant, and expensive sites–Siberia, the Arctic, offshore, and deeper into the earth.

One reaction to those developments has been to begin to treat fossil fuels as scarce and valuable resources that should not be wasted. This new vision has led Soviet planners to cast about for ways to reduce energy waste and to increase the efficiency of energy utilization. These efforts now have taken on the aspect of a national campaign and have been incorporated into the economic planning process. As an example, conservation activities were expected to result in total energy savings in 1980 of over 100 million metric tons of standard fuel (in comparison with 1975 norms)(1). Other goals for savings in 1980 in comparison with 1975 included 50 billion kwh of electricity, 35 million metric tons of boiler and furnace fuel, and 5.5 million metric tons of gasoline(2). The main directions for 1981–85 called for the saving of 160–170 million m.t. of standard fuel per year by 1985, including 70–80 million m.t. saved through decreased consumption norms. (See appendix B, item 1.m.)

The purpose of this section is to present brief descriptions of several Soviet R&D programs that are expected to improve the efficiency of energy utilization. The first four subsections are concerned with various aspects of the production and transmission of electric power—magnetohydrodynamic power generation, ultra-high-voltage power transmission, superconducting power transmission, and pumped-storage hydroelectric power generation. Such attention is appropriate since electric power generation consumes a large fraction of Soviet fuel production: in 1977 thermal power stations consumed about 28 percent of all the primary fuel produced in the Soviet Union(3). The fifth subsection provides a very brief review of a number of other R&D efforts that will affect the efficiency of energy utilization.

MHD Power Generation

Introduction

Magnetohydrodynamic (MHD) power generation is of interest because it offers a way to obtain more electricity from a given amount of fossil or nuclear fuel. According to A. Ye. Sheyndlin, the director of the Institute of High Temperatures (IVT), AN SSSR, Soviet fossil-fuel and nuclear electrical power generating plants operate at overall efficiencies not exceeding 40 percent (4). Conventional technology is no longer able to provide significant improvements in this efficiency. One solution to this problem is the application of MHD technology to directly convert heat energy into electricity.

The purpose of the Soviet MHD program, therefore, has been to develop a practical means of energy conversion that will permit high power output with a conversion efficiency significantly higher than that obtained with conventional thermal power plants. Increases in efficiency gained from MHD technology could range from 10 to 20 percentage points(4).

MHD provides a means of energy conversion in which a conducting fluid is passed transversely through a strong magnetic field. The interaction between the fluid and the magnetic field causes a flow of electrons between conducting surfaces positioned parallel with the flowing fluid in the region of the magnetic field. Linking the parallel surfaces with an external circuit causes an electric current to flow through the circuit. Most MHD generator concepts employ a high-temperature ionized gas as the working fluid, and this gas is cooled as it passes through the generator channel. The temperature drop in the gas as it passes through the channel and downstream ducting produces a very high Carnot efficiency as energy is extracted from the gas.

If the working fluid is the gaseous product of high-temperature combustion, ionization of the gas may be somewhat limited. Therefore, particles of a "seeding" material (having a low ionization potential) are injected into the flow just downstream from the combustor. This action considerably increases the ionization of the gas and, hence, the conversion efficiency.

A working fluid heated by a nuclear reactor also can be passed through an MHD channel to convert the thermal energy of the fluid to electric power. Again, seeding is required in order to obtain the proper degree of ionization.

Description of the Program

Background. The Soviet MHD program began in the early 1960s. Experimental hardware development was confined to the laboratory operation of test channels* until 1971, when the original U-25 MHD installation was completed. Short-period operation of the complete installation was begun in 1971 and has continued for increasingly longer periods up to the present. The U-25 was brought to rated capacity in 1975 and now can operate at 10,000 kw output for up to 250 continuous hours(4). The U-25 reportedly achieved a power level of 20.4 MW in December 1975(5).

During the 1970s, the Soviet effort benefited from exchanges with the United States under the U.S.-USSR joint MHD program. Under this program the Soviets received a large superconducting magnet for the U-25 MHD channel from a U.S. laboratory. This magnet was delivered with much publicity by the U.S. Air Force. The Soviets were also to receive from the United States a new MHD converter (channel section with electrodes) for their U-25. In the joint program they had arranged to have their own electrode materials tested in the American MHD channels. Since the Soviet invasion of Afghanistan, activity under this and other U.S.-USSR exchange programs has dropped to a very low level.

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*For example, the U-02 MHD generator built in 1964.

The experimental U-25 MHD generator was installed in an existing power plant in Moscow and periodically contributes output to the local power grid. Operation of the U-25 represents the world's first demonstration of large-scale MHD power generation.

Figure 9 shows a photograph of the combustion chamber of the U-25 MHD generator. The thermal intensity of this combustion chamber is claimed to be about 300 times more than that in the best boiler units. The direction of flow in the photograph is from left to right, and what is possibly the upstream end of the MHD *channel* may be seen at the extreme right. Most MHD channels have a rectangular cross section to achieve maximum generating efficiency between the flat electrodes on each side of the channel.

Current MHD Programs. Soviet work on MHD currently is focused on the design and construction of the U-500, a 500 MW MHD power plant that is to be built in Ryazan, southeast of Moscow(6). The plant, which is scheduled to begin operation at the Ryazan State Regional Power Station in 1988 (a slippage of three years from the original plan), will have a 250-MW MHD generator and a standard steam turbine(6, 7). The U-500 has been nominally rated at 500 MW, but one report indicates the MHD channel will actually be able to provide 290 MW, while the conventional steam turbine will provide 260 MW. Another report indicates that the conventional portion of the plant will employ a standard K-300 condensing turbine having a capacity of 300 MW(8).*

The USSR Ministry of Power and Electrification is responsible for the construction of the U-500. Seventeen ministries and other agencies are reportedly participating in this development. The U-500 is expected to have an overall plant efficiency of 50 percent and to require 10 to 20 percent less fuel and half as much water as a conventional power plant. At second-generation MHD electric power stations the Soviets plan to install units of about 1,000 MW, with a fuel savings of up to 30 percent, 55 to 60 percent efficiency, reduction in cooling water by 33 to 50 percent, and a sharp reduction in atmospheric pollution(9, 10).

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*Some of the power output goes to supply internal needs, hence the 500-MW rating.

Technical and economic specifications for the U-500 were prepared, under the direction of the Institute of High Temperatures, by specialists of the Moscow branch of the All-Union State Institute for the Design of Electrical Equipment for Heat Engineering Installations (*Teploelektroproyekt*). The U-500 will use natural gas as fuel, and employ a superconducting magnetic system(10, 11). Initial construction of the plant began early in 1982 at the Ryazan State Regional Power Station(12).

During the 1970s the Soviets built special, mobile rocket-powered MHD generators of a type called "Pamir" that produce powerful electric current pulses for long-range seismic investigations. As an example, the "Pamir-1" MHD pulser, which runs on end products of double-base solid fuel with alkaline metal admixtures, can generate 12 to 15 MW of power with each of two channels, producing signals that can be recorded at a distance of 35 to 40 km(13). Thus, seismic studies have become one of the first practical applications of MHD energy conversion. The key personality in this generator development is Ye. P. Velikhov at the Kurchatov Institute. These seismic studies have continued on the Kola Peninsula(14).

In 1977 two key figures in the Soviet MHD program—V. A. Kirillin, then chairman of the GKNT, and A. Ye. Sheyndlin—indicated their belief that nuclear closed-cycle MHD generators can find broad application in nuclear power engineering(15). However, although much work has been done, a great deal of complex research remains before practical MHD generators of this type can be developed. Important studies include characteristics of nonequilibrium plasmas, interaction of plamas with channel materials, pulsed operation and channel design, and superconducting magnet design.

The initial Soviet open-cycle MHD test facilities have burned natural gas (seeded with a potassium compound) since this fuel was plentiful and readily available at the test sites in Moscow. The combustion products of natural gas also appear to be less damaging than

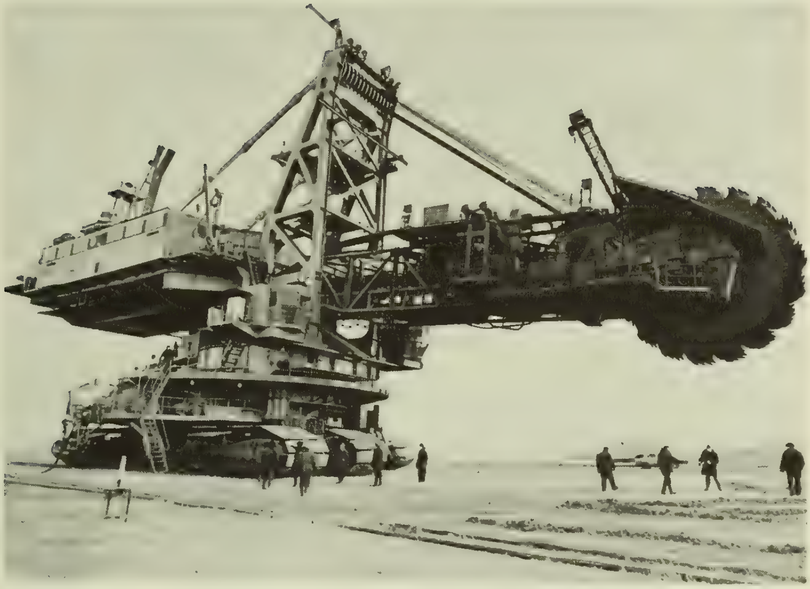

Figure 8 The ERP-2500 Rotary Excavator (photo credit: TASS from SOVFOTO)

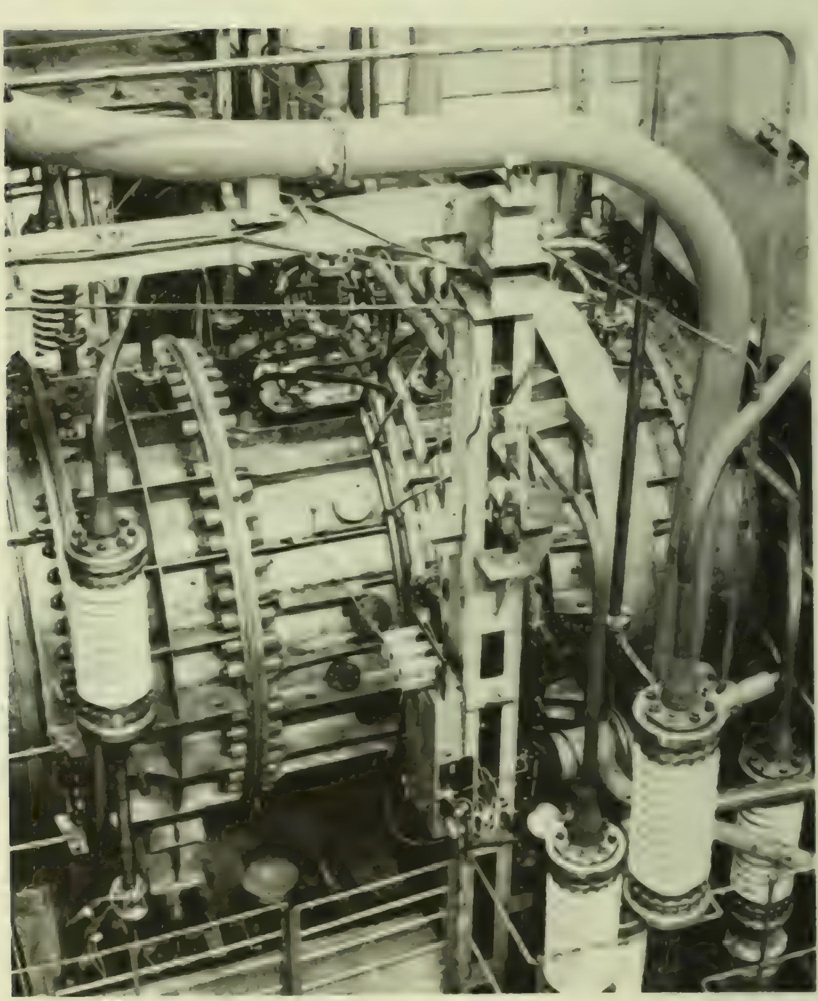

Figure 9 The Combustion Chamber of the U-25 Station's MHD Generator (photo credit: Soviet Export)

those of other fossil fuels to the MHD channel materials and to auxiliary equipment such as preheaters. During the past few years Soviet researchers have begun to study efficient use of coal combustion products in MHD generators and the slagging problem in MHD channels(16). They also have paid close attention to the results of U.S. research with coal-fired MHD channels.

If coal (such as that from the Kansk-Achinsk Basin) can be used successfully as a fuel in MHD generators, it can provide the Soviets with distinct economic advantages over other fossil fuels(17). However, in the present state of the art, an extensive research and development program is needed to determine the proper methods of using coal and the materials requirements for effective design of the MHD power system. Soviet capabilities for building efficient and reliable coal-fired MHD channels and other key components of the system appear to be considerably inferior to those of the United States. The true status of their coal-fired MHD experimental program is not clear. However, in January 1983 Professor V. Ustimenko, deputy director of the Kazakh Scientific Research Institute of Power Engineering, observed that prospects for industrial MHD power stations on a broad scale depend on the utilization of coal fuel, owing to the fuel and power resources situation. He reported in this connection that organizations of socialist bloc countries were taking part in a program of scientific and technical cooperation for the development of MHD power stations operating on gas, liquid, and solid fuels(7). Among participating Soviet organizations, his institute was taking part in a large research project on methods for the highly forced burning of coal, and they were designing combustion chambers for MHD power stations operating on coal.

Whether gas, oil, coal or fissionable materials are used as fuel, MHD power plants would significantly conserve fossil fuel resources. For this reason, the Soviets plan to build plants on a national scale when they are perfected.

Supporting Technologies. Perhaps the most important technological area requiring further development for successful design and operation of MHD generators is the field of high-temperature ceramic materials. Since the early 1960s many compositions and methods of preparation have been utilized in experimentation under MHD channel operating conditions. The most critical channel components needing improvement are the electrodes to carry the power output and the insulation segments used to separate the electrode surfaces. Certain combinations of ceramic materials have shown particular promise, even under the slagging conditions produced by coal combustion. However, recent experimentation seems to indicate the desirability of preparing the cathode segments from metal alloys rather than ceramic materials(4).

Another important area of technology needing further development is that of high-parameter superconducting materials and flexible, stabilized windings of these materials for the magnetic system. Also, magnet design in conjunction with improved cryostat design needs further study and experimental evaluation. Use of the large superconducting magnet in the Soviet U-25 installation during subsequent test operation will indicate the effectiveness of the materials and construction techniques embodied in this unit.

Key Organizations and Personalities

The leading Soviet research facility in MHD appears to be the USSR Academy of Sciences' Institute of High Temperatures (IVT) in Moscow. IVT is directed by A. Ye. Sheyndlin, one of the Soviet Union's most prominent scientists and administrators of research.*

Other primary Soviet MHD research facilities exist at the GKAE's Institute of Atomic Energy imeni Kurchatov (IAE) and the Institute of Power Engineering imeni Krzhizhanovskiy (ENIN). IAE has led Soviet research efforts in closed-cycle MHD energy conversion. The key personality in this work has been Ye. P. Velikhov, who is now a deputy director of IAE and is also a leading personality in the Soviet program for controlled nuclear fusion.

ENIN has pursued various programs dealing with fossil-fuel-fired MHD and is presently perhaps the leading Soviet facility for coal-fired MHD research. In one research effort, pulsed combustion techniques have been employed in order to reduce channel-wall temperatures and to optimize the ionization of the working medium(19). Other combustion studies have dealt with the disposition and effects of slag from burning coal(20).

In an effort to better plan and coordinate work in MHD and related

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*In 1981 Academician Sheyndlin was named chairman of the coordinating council for the problem "Synthetic Fuel"(18). See chapter 5 for Sheyndlin's activities in this role.

Table 13 Key Organizations and Personalities Engaged in MHD Research

- Institute of High Temperatures (IVT), AN SSSR, Moscow
  - A. Ye. Sheyndlin, director
  - S. I. Pishchikov, deputy director
  - V. A. Bityurin
  - M. A. Styrikovich
  - A. V. Nedospasov
  - V. A. Ovcharenko
- Institute of Atomic Energy imeni Kurchatov (IAE), GKAE, Moscow
  - Ye. P. Velikhov, deputy director
  - V. S. Golubev
  - V. A. Gurashvili
- State Scientific Research Power Engineering Institute imeni G. M. Krzhizhanovskiy (ENIN), Minenergo, Moscow
- Institute of Theoretical and Applied Mechanics, SO AN SSSR, Novosibirsk
- Scientific Research Institute of Nuclear Physics, Moscow State University, MVSSO SSSR
- Institute of Applied Mathematics, AN SSSR, Moscow

fields, two scientific councils have been created under the USSR Academy: Scientific Council on Theoretical and Electrophysical Problems of Power Engineering(21); Scientific Council on the Complex Problem of Methods of Direct Transformation of Thermal Energy into Electrical Energy. Other prominent institutes and personalities are listed in table 13. Note that most of the institutes are located in Moscow. In recent years the MHD field has lost three prominent researchers—B. Ya. Shumyatskiy of IVT and Yu. M. Volkov of IAE died in 1982, while E. E. Shpilrayn, who once was prominent in MHD work, recently has been publishing articles on solar energy(22, 23).

Evaluation of the Program

Level of Effort. Little information has been released on funds or manpower supporting MHD work, but what is available suggests that the program has been well funded. A Western analyst, G. Rudins, estimates that Soviet expenditures up to 1974 totaled the equivalent

(JPS). The Soviet Union has eleven JPS's covering the following areas: the Northwest, the Center (area around Moscow), the South, the Middle Volga, Northern Caucasus, Transcaucasus, the Urals, Northern Kazakhstan, Central Asia, Siberia, and the Far East.

At present nine of the JPS's are tied into the Unified Power System (UPS) (i.e., all except the Central Asian JPS and the Far Eastern JPS). The UPS now encompasses a total area of 10 million km^2 with a population of nearly 220 million people and unites eighty-eight of the ninety-seven power systems of the USSR. Only the two JPS's mentioned and several power systems in remote regions remain isolated from the UPS; in 1979 power stations of the UPS accounted for 82 percent of the installed capacity and 88 percent of the electricity generated in the USSR(29).

It has been a technological challenge for the Soviet Union to pull this far-flung electricity empire together into a unified system. Over the years the Soviets have been gradually increasing the voltage of their long-distance transmission lines, going to hundreds of kv as the distance became greater than 100 km and the power reached as much as 100 MW. The first Soviet 500-kv line was constructed in 1959, and the first experimental 750-kv line was built in 1966(30). During the Ninth Five-Year Plan (1971–75), 750-kv AC lines were introduced into practice.

To form the present unified system, JPS's and regional systems are tied together with high-voltage transmission lines of 220-750 kv AC and 800 kv DC. The main AC voltage level for system interties in the UPS is 500 kv. In the South and the Northwest JPS's, 330-kv AC interties have been used in the past, but a network of 750-kv AC lines is being developed. At present, a 750-kv AC system intertie connects Leningrad and Moscow, and a second line of this voltage runs from the Donets Basin (Donbass) to the Western Ukrainian substation and on to Albertish, Hungary (linking the USSR and CMEA unified power grids)(29). Thus, 750 kv is the highest AC voltage presently in use in the USSR.

To date, the USSR has built only two DC transmission lines. The newer and larger of the two is an 800-kv line between Volgograd and the Donbass. Commissioned in stages over the period from 1962 to 1965, this line is scheduled to be overhauled within the next five years in order to upgrade its equipment(31). Experience gained in the construction and operation of the 800-kv line is being used to develop DC lines of even higher voltages.

One problem that is increased by creating large-scale power transmission lines is the problem of power losses in the grids. Losses for the USSR during the period 1965–75 rose from 6.9 percent to 8 percent of total electricity transmitted(32). By 1976 line losses had risen to 9.1 percent. The goal for 1980 was to reduce line loss to 8.6 percent(33).

Among the principal reasons for grid losses in the USSR are the length of power lines, which are strung over great distances in this vast country; large daily temperature variations; a greater number of steps of electricity transformation in connection with an increase in grid voltage and the development of extra-high-voltage trunk lines to connect joint power systems; an insufficient level of reactive power compensation in grids and in power-consuming installations; significant deviations of frequency and voltage from normal parameters; and an increase in power line loads beyond efficient levels(34).

The need to ship power from fuel-rich Siberia to the European USSR and increased line losses have made clear the need for introduction of extra-high- and ultra-high-voltage power transmission lines (UHVPTL) such as 750-kv, 1,150-kv, and 1,500-kv lines. Soviet efforts to develop such UHVPTL lines are discussed below.

Description of the Program

Current Status. The purposes of Soviet R&D on ultra-high-voltage power transmission are (1) to move power within the Unified Power System in a more efficient manner, and (2) to enable the Soviets to construct a system of power lines by which they can efficiently transmit electrical power from the areas in Siberia and Kazakhstan where fossil fuels and hydroelectric power are plentiful to highly industrialized areas in the European USSR and to populated areas where fossil fuels are scarce. The discussion that follows is devoted primarily to the second of these purposes—sometimes referred to as the "coal-by-wire" option.

In pursuit of the "coal-by-wire" option the Soviets have been conyear of the Kansk-Achinsk coal for power generation and long-distance transmission(48). Late in 1984 this project was still being mentioned, but the voltage level had been raised to 3,000 kv(43).

Supporting Technologies. The following technologies appear to be most important in support of UHVPTL development:

(*a*)Design technology for high-voltage AC rectifier units (thyristor valves)
(*b*)Conductivity of specially selected gas mixtures (elegas conductors)
(*c*)High-voltage insulation materials
(*d*)Design technology for high-rated transformers and capacitors
(*e*)Overvoltage protection and automatic reclosing
(*f*)Solid conductor materials
(*g*)Tower design
(*h*)High-voltage switching
(*i*)Corona effects and radio interference
(*j*)Lightning protection.

Development of these technologies and work on related design problems have been taking place, and significant progress was made in most of these areas during the 1970s and early 1980s.

R&D Establishments and Personalities

The R&D effort in support of the Soviet UHV program has been a broad-based one involving numerous research organizations of the USSR Ministry of the Electrical Equipment Industry (Minelektrotekhprom), the USSR Ministry of Power and Electrification (Minenergo), the USSR Academy of Sciences, and higher schools. A key organization in this effort is the All-Union Electrotechnical Institute imeni Lenin (VEI) of Minelektrotekhprom, Moscow. This institute has been called the chief developer of equipment both for UHV AC and for UHV DC lines. The institute has a test facility in Tolyatti and is constructing a new high-voltage research center with a modern test facility in Istra. Another test facility is Minenergo's Scientific Research Center for Testing High-Voltage Equipment, Moscow, where equipment was being tested that was scheduled to go into service on the 1,150-kv Ekibastuz-Urals line in 1982(49).

Other organizations engaged in UHV R&D or implementation, and the thrusts of their work, include:

Scientific Research Institute for the Transmission of High-Voltage, Direct-Current Electric Power, Leningrad—insulation for UHV AC lines, conductors for UHV DC lines(50)

All-Union Scientific Research Institute of Power Capacitor Building, Serpukhov—capacitor for UHV DC lines(51)

All-Union Scientific Research, Project Design, and Technological Institute of Transformer Building, Zaporozhye—transformers for UHV DC lines(52)

Leningrad Polytechnical Institute imeni Kalinin, Leningrad—problems of developing 1,150-kv and 1,800-kv AC lines(42, 53)

All-Union Scientific Research Institute of High-Frequency Currents imeni Vologdin, Leningrad—thyristor device for UHV DC(49)

All-Union Scientific Research, Project Design, and Technological Institute of the Cable Industry

All-Union State Project Survey and Scientific Research Institute of Power Systems and Electrical Power Networks (Energosetproyekt)

Institute of Physics, Azerbaydzhan Academy of Sciences.

The work is evidently coordinated by the Ministry of Power and Electrification and the GKNT.

Key personalities include G. N. Aleksandrov of the Laboratory of Very High Voltage at Leningrad Polytechnical Institute(36, 37, 42) and Ye. Marchenko, the director of the Scientific Research Institute of Direct Current Sources in Leningrad(47).

In the mid-1970s a U.S.-USSR coordinating committee for S&T cooperation in the field of R&D on EHV and UHV power lines was set up. A joint U.S.-USSR R&D effort with selected programs was completed by the end of 1977(54). Since the invasion of Afghanistan, activities under such cooperative programs have fallen to very low levels or ceased completely.

Rivalries. The only direct competitor to the Soviets' UHVPTL program is the superconducting power transmission line development program. However, the UHVPTL technology is in a later stage of development and also appears to hold certain cost and maintenance advantages over the competing technology (SPTL).

Evaluation

It is evident that UHVPT is a priority area of Soviet R&D and energy development. The draft main directions for the Tenth Five-Year Plan called for the construction of 1,150-kv AC transmission lines and the development of equipment for 1,500-kv DC lines(55). (See also appendix A item 1j.) The Eleventh FYP draft main directions also mention UHV power transmission, calling for the 1,150-kv AC line from Ekibastuz to the Urals to be put into operation, along with the first section of the 1,500-kv DC line from Ekibastuz to the Center. (See appendix B, item 1a.) The existence of a Scientific Council on Power Engineering and Electrification under the GKNT with responsibilities for supervising UHVPT is a further sign of official interest in this technology. (See appendix D, item 2.)

The construction of UHV power lines of 1,150 kv AC and 1,500 kv DC signifies a qualitatively new level in Soviet power engineering—a transition to what is still largely an experimental technology, both in Soviet and world practice. In the case of the 1,500-kv DC line, all equipment reportedly was developed in the USSR and will be produced at Soviet plants(56). Nevertheless, apparently not all technical problems of UHV have been solved. For example, at least one Soviet expert sees the need to hasten the development of new reactive-power compensation devices to maintain voltage levels and reduce energy losses in lines of 1,150 kv (and also 750 kv)(29). In the development of UHV DC transmission, the major problems have centered on circuit breakers and, especially, converter equipment(30). Soviet experts seem to be confident that these problems have been or will be solved.*

We do not see any insurmountable obstacles in the way of developing this technology and believe it should be possible for Soviet researchers to establish the technical feasibility of UHVPT before 1990 and, with sustained effort and good fortune, even before 1987. Determination of technical feasibility is likely to come first with the lower voltage lines. The extent of application of UHVPTL, of course, will depend on both technical and economic considerations. At present it seems likely that UHVPTL will prove economically attractive for certain large-scale transmission efforts (e.g., moving electric power from Siberia to the Urals or even to the Center), but it is less certain that the technology will be applied in more routine transmission tasks.

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*A major reason for the planned overhaul of the 800-kv Volgograd-Donbass DC line is to replace less efficient mercury-arc converter equipment with more advanced thyristor devices(31). Similar devices reportedly have been developed in the USSR for the 1,500-kv Ekibastuz-Tambov line(57).

Superconducting Power Transmission

Introduction

Superconducting power transmission offers the basic potential to distribute electric power in large amounts over long distances with minimal expenditure of energy. Since the Soviets plan to transmit power thousands of miles from remote areas where fuel is plentiful (e.g., Siberia) to industrialized areas in the European USSR, this new technology, if developed, may provide important economic advantages.

Description of the Program

Ye. L. Blinkov, head of the Cryogenic Electric Power Division, State Scientific Research Power Engineering Institute imeni Krzhizhanovskiy (ENIN), envisions the use of superconducting power transmission lines (SPTL) to create a single, unified power system. According to Blinkov, a closed system of such lines encircling the country could serve as a huge energy storage system in which electric current could circulate with very low losses, to be used as necessary(58). Blinkov stated in 1977 that "according to our calculations, the efficiency of the superconducting cable is greater than 99 percent." He pointed out that one cable of this type, constructed to an optimum size, would be capable of transmitting almost the entire peak power of the Moscow power system(59). The Soviets envision not only AC and DC SPTL but also superconducting magnetic systems to offset voltage fluctuations by energy storage(60, 61). In pursuit of these goals a number of experiments with short test cables have been conducted. The All-Union Electrotechnical Institute imeni Lenin (VEI) and the All-Union Scientific Research Institute of the Cable Industry (VNIIKP) have collectively developed both AC and DC cables and have tested cables up to 150 m in length. Nb_3Sn (commonly called "niobium-tin") has predominated as the superconductive material chosen for test cables.

Since 1973 ENIN has been developing a 100-m rigid AC superconducting cable for testing at the "Kozhukhovo" substation of the Mosenergo system. VNIIKP has proceeded with the development of a flexible SPT cable and obtained a 50-m DC SPT prototype cable for testing beginning in 1978(62, 63). As of 1979, experimental cables up to one kilometer in length were being built(64).

Supporting Technologies. The primary supporting technologies appear to be the following:

(1)Preparation of current-carrying elements in the cable
(2)Use of electrical insulation in the cable
(3)Thermodynamics and fluid flow in the cryogenic passages
(4)Superconductive switching and load balancing of the line
(5)Cryogenic refrigeration
(6)AC vs. DC operation.

It appears that all of these technologies are being studied or developed in the research facilities discussed below. These technologies are utilized in the prototype design and design optimization studies of cable structures that also are being carried out at various Soviet facilities.

Key Organizations and Personalities

The establishment of a joint U.S.-USSR exchange program on SPTL suggests that the program has enjoyed the active approval of the USSR Council of Ministers. There is also a possibility of significant support and encouragement from the Soviet Ministry of Defense.

The Soviet SPTL program is supported by the GKNT and the USSR Academy of Sciences. The Academy monitors SPTL research through its Scientific Council on the Complex Problem "Research on the Use of Superconductivity in Power Engineering," which is chaired by D. G. Zhimerin(58). Zhimerin, who formerly headed ENIN, was a first deputy chairman of the GKNT(65). In his former post he was in a good position to influence the allocation of resources to this program.

The subsequent director of ENIN (since 1974), V. I. Levitov, is a member of the Council of Cryogenic Power Systems and Transmission Lines under the GKNT. Levitov was directly involved in the joint U.S.-USSR Coordinating Committee on Scientific and Technical Cooperation in the Field of Superconducting Power Transmission, being head of the Soviet delegation to this committee. Levitov was formerly a specialist in high-voltage power transmission(66).

Other institutes carrying out significant SPTL development work are the All-Union Electrotechnical Institute imeni Lenin (VEI), Moscow, and the All-Union Scientific Research Institute of the Cable Industry (VNIIKP), Podolsk. The latter two facilities are reported to be under the Ministry of the Electrotechnical Industry(62).

Several other research institutes are supporting the Soviet SPTL program. These appear to include at least the following(62):

(1)Kriogenmash (cryogenic refrigerators)
(2)Metallurgical Institute imeni Baykov
(3)Institute of Metrological Services
(4)Institute of the Physics of Metals (Kiev)
(5)Physical-Technical Institute of Low Temperatures.

The Physical-Technical Institute of the Ukrainian Academy of Sciences, Donetsk, might also be added to this list. In the mid-1970s this institute was developing a process for hydrostatic extrusion of superconductors of a type suitable for SPTL(67).

The key Soviet program that is in competition with the SPTL program is that for ultra-high-voltage power transmission. There are some indications of skepticism within VEI and VNIIKP as to whether SPTL shows more economic advantages than does ultra-high-voltage power transmission.

Evaluation

Likely Fields of Application of Results. The major application of SPTL would be in long-distance transport of electric power as a means of reducing transmission losses. As noted in earlier portions of this book, there is especially great interest in the Soviet Union in finding more efficient means of moving electricity from fuel-rich Siberia to the industrial areas of European USSR. However, SPTL could well find application in transmission over shorter distances and as a means of better linking the various regional power grids.

Significance of the Effort. While the Soviet SPTL effort appears to enjoy substantial support, it cannot be characterized as an "all-out" effort, nor as one of the major Soviet energy R&D programs.

A joint U.S.-USSR program on SPTL technology evolved from an agreement on cooperation in the fields of science and technology signed by the heads of the two countries on May 24, 1972. The SPTL exchange continued under the 1974 Energy Agreement, with the objective of attaining more rapid progress in SPTL technology through cooperation than might occur if each national program operated independently(62). In recent years, with increasing tensions between the United States and the Soviet Union over Afghanistan and Poland, activity under the joint program has practically ceased.

Judging from indications during the U.S.-USSR exchange program for SPTL, the manpower assigned to the Soviet program is significant, but not comparable to that utilized in their MHD program, for example.

It has been reported that U.S. members of the Organizing Committee for the joint program were told at the first meeting (Moscow 1973) that the direct Soviet effort in SPTL development involved two hundred persons. More recent estimates suggest 300 to 350 people are engaged in Soviet SPTL work(62).

Soviet publications on SPTL development per se have been infrequent. There also has been a moderate number of publications on SPTL-related technology.

D. G. Zhimerin, mentioned above, has stated that a coordinating center of CMEA countries for design and development of cryogenic electric power transmission lines—Interkriolep—had been organized in Moscow (prior to early 1977)(58).

Economic Considerations. The technical feasibility of SPTL has been demonstrated, and small sections have been tested to prove out initial design concepts. A considerable number of parametric studies were carried out during the 1970s to assist in determining optimum design.

In general, it appears that SPTL may be economically advantageous in some applications at power levels of 2 GW and up. Ye. L. Blinkov et al., of ENIN indicated in 1974 that regardless of the variation in approaches to calculating the material costs and electrical energy, etc., the majority of authors feel that superconducting cables are competitive with cryoresistive and oil-filled cables, beginning at power levels of 2 to 2.5 GW(68). Blinkov et al. found the optimum temperature range to be 6.2 to 8.2°K (from the standpoint of minimum refrigeration costs).

According to G. G. Svalov, head of the department of superconducting cable products of VNIIKP, the new technical capabilities presented by cryogenic power transmission lines will make it possible to meet the economy's demands up to the end of the century. The use of SPTL is seen as increasing the efficiency of power transmission lines from 95 to 99.5 percent, thereby yielding savings of hundreds of millions of rubles, and making thousands of hectares of land available for other purposes. It will also become possible to lay high-voltage lines into the heart of downtown city areas(69).

Time Frame for Development. Initial Soviet research regarding the practicality of SPTL apparently began around 1967(62). While the Soviets have made progress in their R&D efforts since 1967, it is clear that much more work is needed. Soviet implementation of SPTL for civil power transmission depends on at least three factors: (1) demonstrated superiority over UHVPTL in power distribution applications; (2) reduction in cost of high-technology components of the SPTL system; (3) demonstration of SPTL system safety and reliability.

At this time we do not believe that a commercial superconducting power transmission line is likely to be in operation before the end of this century.

Pumped-Storage Hydroelectric Power Generation

Introduction

The Soviet Union, like other countries, encounters major inefficiencies in the production and consumption of electric power due to variations in the demand for electricity during the course of a day, week, and year. During peak-load periods (e.g., during working days), demand rises to high levels that can be met only by placing all (or most) generating units in service, including those that are old, inefficient, or use expensive fuels. But when the load declines (e.g., late at night or on holidays), demands may fall to levels below those that can be handled by large, efficient baseload plants. In the USSR's central region, northwest, and southern European territory, for example, the nighttime load is only 55–60 percent of the maximum(70). As a result, when demand is low, the system has unused capacity to produce inexpensive electricity, while during peak-load periods the marginal cost of electricity may be very high.

At one time this problem was not of great concern in the USSR because of the heavy weight of industry in demand and the practice of operating multiple shifts. But in recent years, consumers with less even demand patterns, such as private citizens, commercial establishments, and agriculture, have come to account for a large share of total demand, and the load management problem has become more complex. To illustrate, in 1960 industry accounted for 64.6 percent of useful electricity consumption; by 1980 industry's share had dropped to 54.6 percent(71). The increased importance of the private consumer can be better appreciated from the 1981 estimate that 1,200 MW of capacity are required just to handle evening television watching in Moscow(72).

Furthermore, increasing emphasis on nuclear power plants in the European part of the USSR has compounded the problem because these plants are best suited to a baseload mode of operation.*

As of 1981, most peak loads within the Soviet Union's many power systems were handled by thermal stations. However, existing Soviet equipment is not well adapted to a peaking role. Fuel consumption rates are high, equipment wears out prematurely, and accidents are frequent(73).

An obvious answer to this problem is to develop a means of storing electricity produced in off-peak periods for use during subsequent peak-demand periods. One approach is to use the baseload plants to pump water into an elevated basin during periods of low demand (e.g., at night) and then release the extra water into a hydroelectric turbine during peak-demand times (generally, mornings and evenings)(74). Alternatively, one can pump water from an underground reservoir and then release the water to fall back into the underground receptacle when power is needed.

Description of the Program

Pumped storage has been widely adopted in the United States, Western Europe, and Japan. In the United States, for example, the first unit (32 MW) was the Connecticut Light and Power Company's Rocky River Plant, which began operations in 1929(75). The Soviet Union was slower to adopt this technology because of its abundant supplies of fossil fuels and its relatively flatter load curve. Not until the early 1970s did the USSR commission its first "hydro-storage electric power station" (GAES)—a 225-MW installation that was added on to an existing 350-MW hydroelectric station (GES) on the Dnieper River north of Kiev(38). The Kiev GAES, which generally is referred to as an experimental facility, has reverse pump turbines that pump water into the upper reservoir for seven hours per day and then generate electricity for four hours per day(73).

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*For a discussion of efforts to develop load-following nuclear power stations, see chapter 3.

A second plant—the Zagorsk GAES—has been under construction in the general vicinity of Moscow since 1975. The plant's total capacity of 1,200 MW will be provided by six units of 200 MW each. As with the Kiev GAES, water will be pumped for six to seven hours per day, and electricity will be produced for four hours. Under this regime, the plant will generate 4 to 5 million kwh per day(74). The plant was to come on line in 1983 and be at full capacity by the end of 1985(72).

A third plant—the Kanev GAES—is under construction on the

Table 14 Existing and Planned Pumped-Storage Power Plants

Name	Location	MW	Status
Kiev	Dnieper River Vyshgorod	225(38)	Completed 1971(81)
Zagorsk(73), (74)	Kunya River(74) Moscow Oblast(78)	1,200(74), (79)	Under construction(74) First unit in 1983(72)
Kayshyadoris	Neman River(80) Lithuania	1,600	Under construction(74) First unit in 1985(82)
Leningrad	Shapsha River(78)	1,360	Under construction
Central	Kalinin Oblast(78)	–	–
Dniester(78)	Dniester River	2,160	Planned
Konstantinovskaya(70)	South Bug River	380(70)	Planned
Kanev	Dnieper River	3,600	Planned(78)
Minsk	–	Over 1,000(76)	Planned(76)
Tereblitskaya	–	1,350	–
Tereblya Rikskaya	–	2,025	–

Sources: References (73) or (79) unless noted otherwise.

Dnieper River and will have 3,600 MW of capacity. When completed, it will save almost 10 million m.t. of standard fuel per year(73).

At least ten construction sites have been selected for GAES, and construction is under way at several other locations, including the Kayshyadoris GAES in Lithuania and a site near Leningrad(76). Information on the known plants and sites is presented in table 14.

Although hydroelectric power technology is well established, the move to build pumped storage plants has forced the USSR to conduct additional R&D. The Soviets are working on means for making the huge water-conducting pipes out of steel-reinforced concrete rather than steel. A special experimental plant for this purpose was reported to be under construction in early 1982(74). The Soviets also have faced problems in building foundation pits (up to one hundred meters deep) in flooded earth where "earth creep" can be a major difficulty(72).

Most of the GAES that are under construction involve installations in which both reservoirs would be aboveground. However, the Soviets also are considering building underground pumped-storage plants wherein water would move between a reservoir located underground and one on the surface. This approach would have the advantage of allowing construction in lowland areas (where most Soviet industrial facilities and cities are located) and would not require the withdrawal of large amounts of land from agriculture, forestry, or other productive uses. However, an underground GAES would require more materials and more electrical equipment. Preliminary design work has been carried out at Gidroproyekt and at the "Leningrad Metals Plant" Production Association(77), and it has been reported that an underground GAES with a one-kilometer deep shaft will be built in the Minsk area(76).

We have not found a Soviet agenda for R&D work on underground GAES, but Western specialists believe that further R&D is needed before the concept can be successfully commercialized:

> Research should be conducted to improve equipment and construction techniques for excavating large-diameter deep shafts and large underground caverns. Geological studies are needed to define, evaluate, and determine criteria for suitable lower reservoir design and stability, emphasizing the stress conditions of the surrounding rock. Techniques should be developed to determine underground geotechnical conditions with surface detection methods.

Other areas mentioned include work on turbines and pumps(94).

The Soviets also are working on peaking units based on compressed air. Here, offpeak power would be used to force air into large underground caverns. During periods of peak demand the compressed air would be released, turning gas turbines to generate electricity. In late 1982 a plan for an air-storing gas turbine power plant (VAGTE) with a capacity of approximately 1,000 MW was reported to have been drawn up(83).

One of the more interesting pumped-storage stations is the Konstantinovskaya GAES that is to be built on the South Bug River in the Ukraine. This 380-MW station will be part of the South-Ukrainian Power Complex, which will include a nuclear power plant (the 4,000-MW South Ukrainian NPS) and a conventional hydroelectric station (the 1,800 MW Tashlykskaya GES). The close proximity of these three power plants will make it possible to integrate the cooling of water from the NPS with the movement of water through the hydroelectric and pumped-storage plants(70). This should improve the efficiency of cooling water from the NPS and reduce winter ice buildup at the GAES—a problem noted in connection with the Kiev GAES(81).

Key Organizations

Soviet work on GAES is being led by the USSR Ministry of Power and Electrification (Minenergo). Because such work clearly is close to the commercial stage, we would single out Minenergo's Gidroproyekt as the most important organization in Soviet work on pumped-storage hydroelectric power generation. A second Minenergo institute involved in the effort is the All-Union Scientific Research Institute of Hydraulic Engineering imeni Vedneyev (VNIIG). Other participants include two institutes subordinate to the USSR and RSFSR ministries of higher and specialized secondary education (MISI and MEI, respectively). Production facilities providing equipment include the "Elektrosila" Plant and the "Leningrad Metals Plant." (Full names of these organizations are listed in table 15.)

Seven ministries are involved in Soviet efforts to develop compressed-air power plants under the leadership of the USSR Academy of Sciences' Scientific Council for Interdisciplinary Energy Problems. The Council's Thermal Power Section is the specific lead organiza-

Table 15 Key Organizations Involved in the Development of Pumped-Storage Hydroelectric Power Generation

All-Union Scientific Research Institute of Hydraulic Engineering imeni B. Ye. Vedneyev (VNIIG), Minenergo, Leningrad
Moscow Power Engineering Institute (MEI), MVSSO RSFSR, Moscow
Moscow Institute of Construction Engineering imeni Kuybyshev (MISI), MVSSO SSSR, Moscow
"Elektrosila" Plant(91)
All-Union Scientific Research Institute for Planning of Hydroprojects imeni Zhuk (Gidroproyekt), Minenergo, Moscow(76, 77)
"Leningrad Metals Plant" (LMZ) Production Association(76, 77)

Note: All six organizations also are discussed in reference(84).

tion, and Academician M. Styrikovich has been associated with this work. The general designer for the work will be Teploelektroproyekt —the All-Union State Institute for the Design of Electrical Equipment for Heat Engineering Installations(83).*

Evaluation

Although the Soviets are starting to implement this technology at a late date, they have ambitious plans. During the Eleventh Five-Year Plan (1981–85), the Zagorsk GAES is to reach full power, while the first four units (200 MW each) at the Kayshyadoris GAES were to come on line.** Furthermore, construction is to begin on five pumped-storage plants having a capacity of 11,300 MW: the Leningrad, Central, Dniester, South Ukrainian, and Kanev stations(78).

Pumped storage plants offer substantial opportunities for saving standard fuel; estimated annual savings for selected plants are Zagorsk GAES, 200,000 m.t.(72); Kayshyadoris GAES, 500,000 m.t.(80); Kanev GAES, 10,000,000 m.t.(sic)(73).

Estimated savings depend on a number of factors, including the

*As noted earlier in this chapter, Teploelektroproyekt prepared the specifications for the U-500 MHD installation.

**More recent plans call for the first set at the Kayshyadoris GAES to come on line late in 1985(82).

capacity of the GAES, the number of hours of operation per year for the GAES, its efficiency in pumping and generation, and the alternative means of supplying peak power. Thus, in comparing expected fuel savings from the Kayshyadoris GAES with savings from the Zagorsk GAES, the reader will note that the larger plant (Kayshyadoris) is expected to save 2.5 times as much fuel, although its installed capacity will be only one-third greater (see table 14). Part of the difference is explained by the 25 to 50 percent higher operating rate for Kayshyadoris GAES—five to six hours per day(85) vs. four hours for the Zagorsk GAES(74).

It is evident that there are believed to be economies of scale in the construction of pumped-storage plants, as indicated in the following figures on installed capacity and capital investment per kilowatt of capacity(85):

GAES	Capacity	Capital Investment, R/MW
Kiev	225	184
Zagorsk	1200	163
Kayshyadoris	1600	144

GAES development appears to have high-level support in the government, as evidenced by the publication of a main direction for the Eleventh Five-Year Plan and the period up to 1990: "Undertake the construction of water storage electric power stations in the European section of the USSR"(74). (See appendix A, item 1a.)

Other Programs to Improve the Efficiency of Energy Utilization

The purpose of this subsection is to review very briefly a number of other Soviet R&D programs that should help to improve the efficiency of energy usage. No attempt is made to provide a complete description of the programs and facilities, nor to offer thorough evaluations. The intention is rather to provide the reader with a sense of the breadth of conservation activities under way in the USSR.

Fluidized-Bed Combustion Technology

The fluidized-bed combustion technology is a combustion approach in which a solid fuel such as coal is fragmented into particles and subjected to a strong current of natural or oxygen-enriched air from below while being burned. The name derives from the fact that the coal, together with other solid materials that are present, such as crushed limestone or sand, takes on the physical properties of a fluid. This approach contrasts with the normal system of burning solids in which the solid fuel rests on a fixed bed, such as a metal grate.

The advantage of the fluidized-bed approach is that it brings about a more complete mixing of the solid fuel and air and promotes more efficient combustion. As a result, more of the chemical content of the fuel is transformed into thermal energy. In addition, there is typically less polluting exhaust from such a system. As an example, crushed limestone can be used to absorb sulfur in the coal, thereby preventing its release into the atmosphere.

The Soviets have exhibited considerable interest in fluidized-bed technology for coal gasification, coking and liquefaction (see chapter 5), but they have not shown much interest in adapting fluidized-bed technology for combustion of coal in boilers.

The principal facility working in this area is the Central Scientific Research and Project-Design Institute for Boilers and Turbines (TSKTI) imeni Polzunov in Leningrad.

The Unified Power System

A source of increased efficiency in power generation, and one that is likely to become increasingly more important in the future, is the Soviet Union's Unified Power System (*Yedinaya energeticheskaya sistema*) (UPS). The first step in the formation of the UPS—uniting of a series of regional (*rayonnyye*) power systems into interconnected (*obyedinennyye*) power systems—has generally been completed. In 1977 the UPS consisted of ninety-four regional systems grouped into eleven interconnected systems, including the Central, Ural, Kazakhstan, Middle-Volga, South, North-West, North Caucasus, and Transcaucasian interconnected systems. In 1979 the Unified Power System accounted for 82 percent of the installed capacity and 88 percent of the electricity generated in the Soviet Union(29). Ultimately, the UPS is to include the interconnected systems in Siberia, Central Asia, and the Far East.

The UPS will enable the Soviets to improve the efficiency of power generation in the short run by enabling one grid to obtain power from another grid to meet peak demands instead of firing up its own low-efficiency generators; in the long run, it will reduce capital investment in additional power-generating capacity at individual plants. Such capital savings will be made possible by long-term ability to obtain power from other grids during peak demand hours. In this latter regard, extension of the UPS to the east will create a grid spanning several time zones wherein peak load periods would occur sequentially, allowing grids that are at peak load to draw from others that are not.

Energy Conservation by Soviet Industry

An extensive Soviet technical literature on conservation of fuel and power by industry has been produced. Conservation is viewed not only as a means of increasing efficiency of power consumption but as a less costly means of satisfying demand than increased energy production. (According to S. Kutateladze, the director of the Institute of Thermophysics, SO AN SSSR, it costs "one-third to one-half as much to conserve a ton of fuel as to produce and transport it"[86].)

Conservation of energy is especially important in energy-intensive industries such as metallurgy, petrochemicals, chemicals, and pulp and paper. Soviet energy conservation efforts in ferrous metallurgy are of particular interest because ferrous metallurgy is a gigantic consumer of energy: in 1977 it accounted for over 10 percent of all energy source materials produced in the Soviet Union during that year(87). By reconstruction and modernization of existing facilities and introduction of improved technology, total energy consumption per metric ton of steel produced fell from 1,389.3 kg of standard fuel in 1970 to 1,301.3 kg in 1975, or by about 6 percent(88).

The most important type of steel-making furnace in the Soviet Union is the open-hearth furnace (OHF), which, although in decline, still accounted for almost 61 percent of Soviet steel production in 1979. As a result of a shift to larger furnaces, the use of oxygen, and the introduction of the tandem-hearth furnace (THF),* the average fuel consumption rate for Soviet OHFs has been reduced from 263 kilograms of standard fuel* per metric ton of steel (kg s.f./m.t.) in 1940 to 145.7 in 1970 and 134.1 in 1977. According to Kelly, Shaffer, and Spengler, further improvements are possible, and the average fuel rate should be reduced to 117–121 kg s.f/m.t. by 1990(89).

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*A Soviet THF has two hearths instead of one, and each of the two is one-half as large as the hearth of an OHF of equivalent capacity. With this twin-bath design, it is possible to preheat scrap metal in one bath, using the waste heat produced by the simultaneous refining of the scrap and hot metal mixture contained in the other bath(89). This design results in substantial fuel savings.

Numerous goals for energy conservation during the Tenth Five-Year Plan (1976–80) appeared in Soviet publications during that plan period. Since the relationship of one stated goal to others is often not clear, it is difficult to form a detailed picture of Soviet intentions. Nevertheless, one can gauge the magnitude of Soviet efforts from the following brief restatements of several published goals:

Total energy savings in 1980 (in comparison with 1975 norms) were to be 150 to 160 million metric tons of standard fuel.**

The fuel norm in generation of a kwh of electricity was to be reduced from 340 g of standard fuel in 1975 to 325–328 g in 1980. Cogeneration of heat and power was to save 24–25 million tons of hydrocarbon fuel in 1980 in comparison with 1975. Total savings over the Tenth Five-Year Plan were to equal 60 million tons.

In nonferrous metallurgy, increased use of secondary energy resources was to save 2 million tons of standard fuel per year. The Ministry of Nonferrous Metallurgy planned to invest 140 million rubles to achieve its energy conservation goals.

Fuel norms in the production of pig iron were to be reduced by more than 2 percent in 1980 (in comparison with 1975).

We have not been able to determine the success of the Soviets in meeting all of the conservation goals set for the Tenth Five-Year Plan, but they did achieve the target range for consumption of fuel in power generation, lowering the average rate to 328 g s.f. per kwh in 1980. A goal of 319 g/kwh has been set for 1985(78), but the rate achieved in 1983 suggests that they will have trouble reaching that goal:

1940	645 g s.f./kwh
1950	590
1960	468

*One metric ton of standard fuel has a heat content of 27.8 million BTUs or 7 gigacalories.

**Of this total, 42 million tons were to be due to substitution of nuclear energy for fossil fuels in power generation, not conservation in the usual sense.

1970	367	
1980	328	
1981	327	
1982	327	
1983	328	g s.f./kwh
1985	319 (goal). (28, 78)	

Some of the specific conservation approaches being discussed in Soviet publications are presented below. The following list is, of course, indicative rather than exhaustive.

Production, Storage, and Transportation of Fuels

Improve construction of freight cars and operating procedures to reduce current 3 percent loss of coal during rail shipment.

Electric Power Generation

Reduce fuel norms in power generation.
Expand cogeneration of heat and power.
Reduce use of inefficient equipment.
Spread peak loads.
Reduce grid losses.

Transportation

Continue conversion of locomotives from steam to diesel and electric traction.
Increase efficiency of diesel locomotives.
Reduce fuel consumption by commercial aircraft.
Expand use of computers to improve efficiency of freight flow.
Improve mileage of passenger cars.

Industry

Expand use of secondary waste heat in a number of industries.
Improve heat exchange systems.
Improve efficiency of electric motors.
Redesign industrial boilers.
Implement improved vulcanization process.
Introduce improved construction of ladles for casting steel.
Increase efficiency of blast furnaces.
Install automatic control devices in pipe-rolling mills.

Conclusions

Battelle's numerous studies of energy consumption in various industries in the United States, the Soviet Union, and Eastern Europe have convinced us that there is a substantial amount of fat in most economies and, hence, that there are numerous opportunities for conserving energy.

Our conclusion from review of the Soviet technical literature is that there are many opportunities for conservation in the USSR and that there is a substantial effort under way throughout the Soviet economy to improve the efficiency of energy utilization, in general, and to conserve crude oil and other fossil fuels, in particular. The R&D areas discussed in this chapter represent substantial opportunities for conservation, especially in the electric power sector.

Some of the efforts described in this chapter do not appear to be moving rapidly nor to be likely to bear fruit in the near future. Cryogenic power transmission is not advancing rapidly, and the MHD program seems to have lost some of its momentum. Even the pumped-storage program, which requires only limited amounts of new technology, seems to be lagging, with construction deadlines being pushed further and further into the future.

The areas showing the most rapid progress appear to be UHV power transmission and the many, more modest, conservation measures discussed in the last part of this chapter. Numerous signs of activity and success are evident in the latter category. In the field of civil aviation, for example, modifications were made to the TU-134 and TU-154 airplanes during the Tenth Five-Year Plan that led to reductions of 18 to 20 percent in fuel consumption per passenger-kilometer(90). In truck transport there is evidence of a strong shift to large, fuel-efficient trucks powered by diesel fuel. The new ZIL-4331 diesel tractor-trailer, which is to go into production in 1986, reportedly will have a fuel consumption rate that is 30 to 40 percent lower than comparable models(91). In ship transport a new low-speed diesel engine has been tested that offers 12 percent lower fuel consumption rates(92). In ferrous metallurgy increased use is to be made of continuous casting (see appendix A, item 1f).

While one might be tempted to dismiss some of these efforts as exercises in public posturing, there is evidence that the Soviet economy as a whole has become more energy-efficient over time(93). Our conclusion is that such aggregate-level improvements can continue in the future.

Chapter 7 Alternative Sources of Energy

Introduction

Growing concerns about the availability, cost, environmental damage, or safety of the four major sources of energy—crude oil, natural gas, coal, and nuclear power—have led to increased interest in novel sources of energy that seem to offer solutions to one or more of the problems posed by these four energy sources.

This chapter discusses Soviet R&D efforts being devoted to seven novel sources of energy. Three of these—wind, solar, and geothermal power—offer an opportunity to reduce social reliance on limited supplies of depletable resources and to avoid much of the environmental damage associated with fossil fuels. A fourth novel energy source—gas produced by the underground gasification of coal—does not offer an escape from dependence on fossil fuels but is seen as a means of reducing the cost of extracting and utilizing coal, reducing the safety hazards involved in underground mining, utilizing coal seams that are uneconomical to exploit by other means, and converting solid coal into a more convenient form. The fifth fuel considered here—hydrogen—is more appropriately described as an "energy carrier," rather than as a primary fuel, because it probably would be produced from one of the other primary energy sources —nuclear power. Many Soviet scientists are enthusiastic about the long-run prospects for hydrogen, terming it the "fuel of the future." These proponents foresee a gradual transition to a "hydrogen economy" in which motor vehicles, aircraft, residences, and industry will be powered by nonpolluting hydrogen.

The final section discusses Soviet work on oil shale and peat —two energy sources that are not new, but which are being looked at in a new light. Oil shale, in particular, is seen as one base for a possible synthetic fuels industry.

The proposals for these seven energy sources span the gamut from conservative ideas that now are being applied successfully on a modest scale (e.g., the use of geothermal waters to heat greenhouses) to high-risk concepts that will require years to develop and evaluate (e.g., tropopause wind units).

Technical questions remain to be answered in all seven of these energy areas. However, in most cases the critical consideration in the adoption of these energy sources is not technical feasibility but the economics of production, storage, or transportation of the energy form in question. Wind, solar, and geothermal power are likely to be applied in remote, sparsely populated areas of the Soviet Union where electricity and traditional fuels are now expensive, but it is not clear that these new energy sources will find widespread application in the nation as a whole. Oil shale is essentially a local fuel, but synthetic fuels produced from it might find wide geographic application. Underground gasification of coal is an interesting technology but one which is not competitive in the Soviet Union at present, given abundant supplies of natural gas. As a result, this technology will find little application in the USSR during the next several decades, although the technology is being exported. Finally, hydrogen seems to offer a number of advantages as a fuel and could be integrated into the Soviet economy without an unreasonable amount of inconvenience, but it is presently too expensive to produce.

Wind

Description of Programs

Wind power has a long history within the borders of the Soviet Union. Before the Revolution there were roughly 250,000 windmills in Russia and over 2 billion poods of grain were processed in windmills each year(1, 2).* Lenin was in favor of the use of wind power and the Communist government supported numerous projects after it came to power(1, 3). When the famous Central Aero-Hydrodynamics Institute imeni N. Ye. Zhukovskiy (TSAGI) was set up, a department of wind engines was created as part of it. In 1934 a windmill installation with 100 kw of electricity capacity was set up in Balaklava in the Crimea(4). The following decades saw periodic fits of activity in wind power and the development of numerous individual wind-powered devices. However, no viable, well-founded industry emerged from these efforts.

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*One pood equals 36.1 English pounds.

The founding of the "Tsiklon" NPO (science-production association) in 1975 may mark the beginning of a period of more sustained development of wind power in the Soviet Union. Tsiklon was given a franchise to develop, test, produce, and install wind-powered machines and has proceeded to introduce a number of sizes of individual wind machines, and even complete energy systems.

One device that is now in series production is the "Tsiklon-6," a 6-kw wind generator mounted on a tower and powered by a two-bladed propeller with a six-meter diameter. The Tsiklon-6 has automatic controls that can turn it on and off and position the wheel into the wind to maintain optimal blade speed. The Tsiklon-6 can pump three cubic meters of water per hour from a depth of forty meters(5).

Tests have been completed on the Tsiklon-3, Tsiklon-6, and Tsiklon-12,* and the first two of these were in series production as of late 1977(4). Industrial production of the Tsiklon-12 (with 16-kw capacity) was to begin in late 1981 or early 1982, and in August 1983 a synchronous wind generator of this size was reported to be in production at the "Tyazhelektromash" Plant in Frunze(7, 8). A larger unit with capacity of 100 kw—the Tsiklon-24—was in the final stages of testing in April 1978(9). In 1977 it was reported that NPO Tsiklon planned to develop wind power systems with capacities ranging from one to 20,000 kw(4), and by the fall of 1983 engineers at the Volgograd branch of Gidroproyekt were reported to be considering the installation of a 20,000-kw installation on the top of a burial mound near Trekhostrovskaya(10). Finally, in the fall of 1980 a 40,000-kw installation developed by NPO Tsiklon was said to be in a late design stage(11).

Wind installations are being used as a source of electricity in areas that have suitable wind conditions (average annual wind speed of five meters per second or more) and that are removed from centralized power grids(1). The most suitable applications at present are in the powering of devices that do not require large amounts of electricity and that can function on an intermittent basis (e.g., pumping of water for irrigation, land reclamation, watering of livestock, and filling reservoirs of pumped-storage power plants; aeration of fish ponds; desalination of water; and cathode protection of pipelines, offshore oil equipment, and other maritime structures). But there is also an active interest in using wind installations to provide electricity to scientific expeditions and remote settlements (for residential heat, lighting, powering of appliances, etc.). In such applications, storage batteries are used to compensate for the variability of energy produced directly by the wind installation, and diesel-power plants are used for backup purposes.

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*The numbers—3, 6, 12—refer to the diameter of the blade circle measured in meters(6).

The most suitable geographical areas for wind power are considered to be the steppes of the RSFSR, Kazakhstan, Central Asia, the Arctic, coastal areas of the Caspian Sea and the Sea of Okhotsk, the Kamchatka Peninsula, and Sakhalin (1, 2, 12). In 1972 these and other remote areas of the Soviet Union contained 5 million inhabitants who were not on electric grids(13).

In addition to the above work on stationary electric power installations, the Soviets also have been reexamining wind as a source of transportation energy, particularly on ships. The center for this activity is the Nikolayev Shipbuilding Institute (NKI), an educational facility, where a laboratory for the study of vessels with ecologically clean engines (LISED) was organized on a volunteer basis in 1977(14). The activities of NKI researchers have ranged from the testing of multiple-hulled catamarans(15) to preliminary design work on an ore carrier with a cargo capacity of 50,000 m.t.(14). While small sport vessels might be powered entirely by wind, larger ships would rely on a combination of sails and motors(14, 15). In addition to traditional sails, NKI researchers also are investigating wind rotors and adjustable metal sails that could be positioned optimally, thanks to an on-board computer(15, 16). Finally, consideration is being given to sail-powered vehicles that would operate on snow, ice, or sand(15).

Key Organizations and Personalities

A number of organizations have been involved in the development, design, testing, and installation of wind devices over the years, including TSAGI, the All-Union Scientific Research Institute of Electromechanics, the All-Union Scientific Research Institute for the Electrification of Agriculture, the Kharkov Aviation Institute, and the Toguzag Mechanical Plant (under the now-defunct Tselinniy Sovnarkhoz). Soviet efforts to develop wind power have been numerous, but for many years they were not well-focused. As a result, the programs never developed sustained momentum.

In an effort to end this fragmented situation, the All-Union Science-Production Association "Tsiklon" (NPO Tsiklon) was created in 1975. Tsiklon was organized from fragments of previous organizations, including the Central Scientific Research Laboratory for Wind Utilization (TSNILV) and the Department for Wind Power Engineering of the All-Union Scientific Research Institute of Electromechanics(2).

NPO Tsiklon was given broad responsibilities for the design, production, and installation of wind power units and was provided with an array of subunits to assist it in carrying out those tasks(2). Constituent units of Tsiklon included scientific research departments, a central design bureau, test facilities, a factory, and a repair and construction administration(4). The headquarters of Tsiklon and some of its test facilities are located at Istra, 50 km northwest of Moscow(6, 18). Other test facilities are located in Moldavia, in the Kazakh SSR, near Novorossiysk (on the Black Sea), in Astrakhan (at the mouth of the Volga River), and on the Apsheron Peninsula (on the Caspian Sea)(18, 19). Tsiklon's "Vetroenergomash" plant, which has begun series production of several electric power generators, is located at Astrakhan(5).* The Southern Complex Planning and Technological Division of Tsiklon is located in Baku and has the job of installing and servicing wind-driven power units in rural areas of Azerbaydzhan, Dagestan, and Kalmykia(19).

NPO Tsiklon was subordinate to the USSR Ministry of Land Reclamation and Water Management (Minvodkhoz SSSR)(6). In carrying out its activities Tsiklon evidently has interacted with units of the Ministry of the Chemical Industry, the Ministry of Chemical and Petroleum Machine Building, and the Ministry of the Electrical Equipment Industry. The last of these ministries was supposed to supply Tsiklon with electrical equipment needed for wind engines but in

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*As of late 1981, wind-power units accounted for somewhat more than one-quarter of the output of the plant and were to account for one-half by 1985. Other products included desalination units for mineralized waters and field camp equipment(17).

1976 was publicly criticized by the general director of Tsiklon for failing to meet its obligations(2). It would not be surprising if Tsiklon interacted with the All-Union Institute of Agricultural Electrification, but no evidence of such activity was found during this study(3). Finally, Tsiklon had a contract with Kishinev Polytechnical Institute to test wind-power installations on farms in Moldavia(20).

Late in 1981 Soviet press reports began to speak of a new science-production association, the "Vetroen" NPO, which included the Vetroenergomash Plant in Astrakhan(21). An article in June 1982 also referred to the Vetroen NPO and named V. Zelenov as its deputy general director(22). A 1983 article indicated that NPO Vetroen was subordinate to Minvodkhoz SSSR, the parent ministry of NPO Tsiklon, and identified NPO Vetroen as the lead organization for autonomous wind-power engineering(23). The new NPO appeared several months after a very critical article was published in *Pravda* (discussed below), and we have found no mention of NPO Tsiklon after the end of 1981. It is evident that some sort of reorganization took place, but we are unclear about its scope.

The creation of wind aggregates and wind-power systems of large capacity (1 million kilowatts and over) was reported in mid-1983 to be the responsibility of "Gidroproyekt" (All-Union Scientific Research Institute for Planning of Hydroprojects imeni Zhuk)(23). Gidroproyekt is subordinate to the USSR Ministry of Power and Electrification.

R&D on wind-powered vessels is being led by the Nikolayev Shipbuilding Institute, with activity also under way at the Central Scientific Research Institute of the Merchant Marine(14).

While little specific information was found in the course of this study, it can be presumed that the planning of national efforts for the development of wind power and wind R&D are carried out jointly by Gosplan USSR, the GKNT, and the USSR Academy of Sciences. A 1975 article suggests that this planning effort may be led by Gosplan through its Institute for Comprehensive Fuel and Energy Problems (VNIIKTEP), which is tasked with coordinating scientific research on new forms of utilization of energy and forecasting the development of new types of fuel and energy(24). A more specific Gosplan organ for overseeing activity in this area is the Interdepartmental Commission for the Use of Renewable Energy Resources in the National Economy attached to (*pri*) Gosplan USSR (discussed in chapter 2). It is likely that the GKNT participates in these efforts through the Section on Renewable Energy Sources of its Committee on Power and Electrification. We have not found any evidence of Academy involvement in the Soviet wind R&D effort and, considering the nature of this technology, expect to find none.

The most important personality in Soviet wind programs appears to be Vladimir Iosifovich Sidorov. Sidorov has spent most of his career in wind research* and received the USSR State Prize for his work(25). A number of sources identified him as the general director of NPO Tsiklon after its founding, but a June 1978 article indicated that I. A. Babintsev was the general director(26); more recent articles give Sidorov the title of Chief Designer(7, 25). In any case, Valdimir Sidorov remains active and continues to have a significant influence on Soviet work in this field.

The most important organizations and personalities are listed in table 16.

Evaluation of Wind Programs

Level of Effort. In 1972 the Soviet Union had about one hundred people working in wind R&D(13, 27). By 1978 it was reported that NPO Tsiklon alone employed three hundred persons and that the NPO budget was to rise from 2 million rubles in 1976 to 7 million rubles by 1980; additional funds were provided to Tsiklon by other organizations through subsidies to cover portions of the costs of building experimental installations(18).

The wind-powered ship program is of a more modest size, with ten to twelve personnel involved in the LISED laboratory at the Nikolayev Shipbuilding Institute. However, an all-union conference on the subject was held in Nikolayev in 1982(14).

Economic Considerations. According to available reports, the economics of wind power are highly favorable in certain areas of the Soviet Union. One source claimed that the automatic installations being produced by the Tsiklon NPO would pay for themselves in one to three years(28). A later source indicated that the cost of a 2-MW wind power station could be recouped in seven to eight years using conservative assumptions(29).

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*Sidorov's work dates back at least to 1947 when he was awarded an author's certificate for a unit to produce hydrogen from wind(25).

Table 16 Key Organizations and Personalities Engaged in Wind Energy Research

- Interdepartmental Commission for the Use of Renewable Energy Resources in the National Economy attached to Gosplan SSSR
- Science-Production Association "Vetroen," Minvodkhoz SSSR(23)
  - V. Zelenov, deputy general director(22)
  - A. F. Vlasov, director of "Vetroenergomash" Plant (22)
- All-Union Science-Production Association "Tsiklon," Minvodkhoz SSSR
  - I. A. Babintsev, general director
  - A. Ostrovskiy, deputy general director(7)
  - V. I. Sidorov, chief designer(7,11)
  - A. A. Bochkarev
  - P. Bogdashkin
  - V. Balykin
  - N. Kuznetsov(11)
  - V. Rusanov(11)
- All-Union Scientific Research Institute for Planning of Hydroprojects imeni Zhuk (Gidroproyekt), Minenergo(23)
  - V. M. Lyatkher
- Scientific Research Institute for Power Engineering imeni Yesman, Azerbaydzhan Branch(29)
  - R. Mustafayev
- Ministry of the Electrical Equipment Industry
- Kharkov Aviation Institute, MVSSO SSSR
- Kishinev Polytechnical Institute, Moldavian Ministry of National Education
- Ministry of Chemical and Petroleum Machine Building
- Ministry of the Chemical Industry
- Nikolayev Shipbuilding Institute imeni Admiral Makarov, MVSSO SSSR
- Central Scientific Research Institute of the Merchant Marine, USSR Ministry of the Maritime Fleet, Leningrad

As with geothermal power production, wind-power generation looks best when it is compared with electricity production based on diesel power. One writer argues that the cost per kwh of electricity from a wind installation is two to four times less than from a diesel unit(30).

Others claim wind power would be nine or ten times less expensive. In 1983 two wind researchers presented estimates that the cost of electricity from a 20-MW multirotor, wind-driven electric power unit would be about 0.43 kopeck per kwh vs. 4.0 kopecks/kwh for an equal size diesel plant. The authors point to large savings that could be realized in the Far North, especially in northern Tyumen Oblast(31). Of course, one might argue that such comparisons are of limited usefulness since the cost per kwh is notoriously high from small diesel power plants. More impressive is the claim by one source that the cost of electricity from large-scale wind aggregates is expected to be about 0.1 kopeck per kwh in northern, windy areas of the USSR—comparable to the cost of electricity from large hydroelectric plants(18).* It will be interesting to see whether this is the case after such aggregates are actually built.

There are several explanations offered for these favorable economic claims. First, the motive power for the installation (i.e., wind) is free. Second, the new Tsiklon units are almost completely automatic: when the Soviets begin to combine wind installations into aggregates it is planned that one man will be able to run up to twenty wind aggregates(18). Third, wind units are reported to be durable and reliable(2). Agricultural units are planned to last for up to ten years, but some would last for much longer; a wind engine installed in 1940 at the polar station on Vaygach Island, off the north coast of the USSR, reportedly was still operating in 1978(28).

In evaluating such claims, two factors must be kept in mind. First, the Soviets have a tradition of underweighting the interest cost of capital and, hence, making very capital-intensive projects (e.g., hydroelectric plants) look attractive. Second, the economics of a wind installation depend very much on the average wind speed and the variability of wind speed in the area where it is installed. Some Soviet wind units can operate efficiently where average annual wind speeds are as low as 4 to 4.5 meters per second(33). At the other end of the spectrum, most Soviet units must be shut down if the wind exceeds 20 meters per second to avoid structural failures(25). Within

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*Power from the Kola Nuclear Power Plant reportedly cost 0.78 kopeck per kwh in 1976 and 0.74 kopeck/kwh in 1979–80(32). These figures related to *sebestoimost,* a Soviet cost concept that does not include interest charges on capital invested in a facility. Figures on *privedennyye zatraty,* a more inclusive cost measure, were not available.

this range, the power of the wind and its velocity are not related linearly, as Babintsev of NPO Tsiklon has noted: "the power of a stream of wind is proportionate to the cube of its speed. From this it follows that a change of the speed of the wind within the range of 20 percent means a change of its power within the range of 70 percent"(26). Given this circumstance, it is evident that extension of wind utilization outside of areas with steady winds or outside of applications that can tolerate intermittent energy supply will require improved energy storage means (e.g., electrochemical batteries, flywheels, thermal or hydraulic devices, electrolysis of water into hydrogen and oxygen, etc.) or the integration of wind power generators into grids that are large enough to absorb such variations. At present, storage devices account for about 20 percent of the cost of wind-driven electric power installations(26).

Time Frame for Development. According to V. I. Sidorov of NPO Tsiklon, the NPO was scheduled to produce 4,500 installations during the Tenth Five-Year Plan (1976–80) and, by 1990, 150,000 units with a total capacity of 4.5 million kw(4).* Although these are impressive growth rates, official plans do not call for transforming wind power into a major Soviet energy source. According to R. Grünbaum: "The official view of the Soviet Union is that the major application for alternative kinds of energy (e.g., wind power) is in filling strictly local energy demands, mainly in regions where conventional means are more expensive and inconvenient"(18). N. S. Lidorenko, a corresponding member of the USSR Academy of Sciences, and Professor G. F. Muchnik have voiced similar opinions(30).

Nevertheless, there are writers with much greater ambitions for wind power. Some are interested in developing "tropopause" units that would use anchored balloons to tap the winds of jet streams at altitudes of 8–10 km(13, 27, 30). Wind velocities at such heights are three to seven times as great as on the surface. but there are enough engineering problems to keep such generators a number of years in the future(30). Other writers visualize using wind-powered generators to produce hydrogen(25, 26). Some have even suggested that wind power be used to move water from the Black Sea to the Caspian and Aral seas, which are gradually shrinking(4).

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*By comparison, in 1983 the total generating capacity of the Soviet Union was 293.6 million kw(34).

Most important, however, are the proposals for combining individual wind units into entire power grids. Prototypes for such systems already exist: in 1972 there was reported to be a 400-kw wind-power station consisting of 10 units of 40 kw each operating at Kislaya guba on the coast of the Kola Peninsula(13). Another array of twelve units near Tselinograd in northeast Kazakhstan reportedly produced some 11.7 million kwh of electricity over a period of seven years(18). As noted earlier, Gidroproyekt researchers are studying the possibilities of installing a 20,000-kw system near Trekhostrovskaya(10).* Finally, I. A. Babintsev of NPO Tsiklon has discussed proposals for large-scale power grids in northern regions such as the Kola Peninsula, the Shelag Cape, and Chukotskiy Peninsula. According to his estimates, by the year 2000 the Soviet Union could, if it wished, be generating 460–920 billion kwh of electric power per year from wind units and reaping an energy benefit equal to 145–295 million tons of standard fuel(26).

In view of these enthusiastic hopes for the future, it is noteworthy that the Party newspaper, *Pravda*, published a devastating criticism of the current state of affairs in Soviet wind power early in 1981(36). In this article, authored by two doctors of technical sciences and an engineer, it was argued that there were efficient and profitable opportunites to use wind power but that little real progress was being made in the Soviet Union:

> Among the main reasons for this are the unsatisfactory organization and supervision of this matter. There is no qualified design organization capable of creating wind units which respond to the current level of science and technology and which satisfy the requirements of long, reliable operation. Therefore, in particular, mass production of wind generators has ceased. The small plant which was set aside for this purpose in Astrakhan is poorly equipped, and is involved four-fifths of the time in the production of other products(36).

The authors go on to criticize a number of aspects of the Soviet effort, pointing to a shortage of trained personnel, lack of spare parts for wind generators, unsatisfactory performance by NPO Tsiklon, and lack of interest by Tsiklon's parent ministry (Minvodkhoz SSSR) and by its major customer, the Ministry of Agriculture. Production of wind units was estimated at only 150–200 per year (vs. Sidorov's implied goal of 900 units per year during the period 1976–80(4). The authors suggest that the USSR Ministry of Power and Electrification should be given the job of coordinating activities in renewable energy and that an All-Union NPO for the Utilization of Renewable Energy Sources should be established(36).

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*In mid-1983 Hawaiian Electric Co. signed an agreement with General Electric Co. under which the latter is to manufacture and operate a 7,300-kw wind turbine generator that is to be installed on the North Shore of Oahu. The unit, to cost $14.2 million, was to begin operation in 1985(35).

The picture of disarray in this field is further reinforced by a report later in 1981 that the official goal for the Eleventh Five-Year Plan (1981–85) was to produce units with a total capacity of only 5,000 kw(17). This makes Sidorov's 1977 goal of a total capacity of 4.5 million kw by 1990 look highly improbable(4).

Things do not seem to have improved much since 1981. Thirty months after the *Pravda* attack, an article in *Izvestiya* excoriated NPO Vetroen for not having developed a single working wind-power unit in the past six years and for devoting 80 percent of the capacity of its test-and-experimental plant to the production of small wooden houses(37). Another article that appeared at about the same time indicated that NPO Vetroen was producing units with two to four kw of capacity but made no mention of the larger units that have been discussed in the press(23).

In view of the sharpness of the *Pravda* and *Izvestiya* criticisms, the academic degrees of the *Pravda* authors, and the high official organs involved, we doubt that things have been going well with the Soviet effort to harness wind energy or that this area will make rapid strides in the next few years. In fact, the reader may be justified in wondering if this is no more than another of the periodic fits of activity that have characterized Soviet work in this field over the past six decades.

Solar Energy

The use of solar energy received its initial impetus from the photovoltaic achievements brought on by the "space race" of the 1960s. During this period, solar cell technology became highly developed, although primary attention was focused on space applications rather than on the conversion of energy per se. In the mid-1970s, with the emerging concerns about present or impending energy crises, solar R&D efforts came to focus on a variety of terrestrial applications.

In the Soviet Union the principal objective of solar terrestrial energy R&D programs is to determine the practicality of providing thermal energy and electric power in certain areas of the country that have high insolation but that are not able to obtain needed energy in an economical manner from other sources. Secondary objectives are to conserve fossil fuels (especially petroleum) and avoid environmental pollution.

Specific applications being considered include: (1) electric power generation; (2) space heating (residential, commercial, and industrial buildings); (3) solar distillation (e.g., desalination of seawater or brackish waters); (4) solar furnaces (e.g., for the metallurgical industries); (5) drying of agricultural products; (6) pumping of water; (7) water heating; (8) solar air conditioning; (9) photochemical processing.

Since the technical feasibility of most of these applications has been demonstrated over the past two decades, Soviet R&D efforts have concentrated on determining which combinations of applications and geographic areas are economically competitive at present and how the cost of solar energy might be reduced to make it more attractive.

The application of solar energy in the Soviet Union is likely to be limited geographically. Solar energy is most competitive in areas that enjoy intense and steady sunshine and in which other sources of energy are expensive, either because they are remote from traditional sources of energy, are too sparsely populated to benefit from the economies of scale of large electric power plants and transmission systems, or are too mountainous to make it possible to build electric power transmission lines at reasonable cost(26). The most suitable areas of the USSR are probably the sparsely populated areas of Central Asia.

Description of Programs

Solar Electric Power Stations. The Soviet Union's first solar electric power plants (SES) are being developed under a program of the USSR Ministry of Power and Electrification (Minenergo). The plants are to be built near the village of Mysovoye on the Azov Sea coast in the Crimea(38). The capacity of the first (the SES-5) is to be 5 MW, and that of the second—300 MW. In the case of SES-5, 1,600 reflectors, each 5 × 5 meters in size with a total area of 40,000 m^2, will surround an 89-meter tower(39, 40). The automated reflectors, continually reoriented with respect to the sun during the daytime, will direct the sun's rays onto a solar receiver on the tower, which will generate steam to operate turbine generators producing electric power. There also will be a heat accumulator that will store solar energy for use at night and on cloudy days(41). Completion of the first phase of the plant was expected by 1983(18, 27, 42), and the plant was to go into operation by 1985(43, 44).

A possible arrangement of the planned 300-MW station would consist of four units, each with a capacity of 75 MW. Each unit would include a 250-meter tower with 12,000 reflectors, 50 m^2 in size, spread over an area of 2.5 km^2(27, 45). The station is expected to generate 400 to 600 billion kwh of energy in the course of a year. Construction was expected to begin at the end of the Eleventh Five-Year Plan (1985)(46).

Research institutes participating in the project include the All-Union State Design Institute "Teploelektroproyekt" (the general designer), the State Power Engineering Institute imeni Krzhizhanovskiy (ENIN) (scientific direction), and the All-Union Scientific Research Institute of Heat Engineering imeni Dzerzhinskiy(42).

Solar-and-Fuel Power Stations. As an alternative to power stations based exclusively on solar energy, the Soviets are considering stations that would use solar energy and fossil fuels. In May 1982 it was announced that ENIN had developed an engineering conception of a large solar and fuel power station (STES) capable of economic competition with conventional power stations. According to Professor Rustam B. Akhmedov, first deputy director of ENIN, plant parameters have been calculated for the STES. It has been proposed that the station be built in Uzbekistan, using the resources of a small natural-gas field. According to Akhmedov, such power stations offer the advantage of exploitation of deposits of organic fuel that are not included in the fuel-and-energy balance—low-capacity deposits that are remote from major centers of power consumption and unprofitable for industrial development(43, 47).

Other organizations promoting STES development include the Section on Thermodynamic Conversion of Solar Energy (chaired by

Akhmedov) of the GKNT's Scientific Council on the Problem of Utilizing Renewable Sources of Energy, and the Section on the Development and Creation of Solar Power Stations of the Uzbek Republic Commission for Promoting the Acceleration of the Study and Use of Solar Energy in the Economy, under the Central Committee of the Communist Party of Uzbekistan(43, 47).

Professor Akhmedov has asserted that STES will have substantial advantages over purely solar stations of all designs "because of a number of technical innovations, the employment of a fuel backup system, the optimization of the thermal scheme, and improved systems for the storage of energy . . . . Solar-and-fuel stations consume 60 percent less organic fuel than conventional thermal power stations to produce the same amount of electric power. Systems for the thermal storage of energy make it possible to prolong the time that the station operates on solar energy to about 4,000 hours a year" [whereas the Crimean purely solar station will operate only 1,900 hours a year], according to Akhmedov. He compared the capital investment per kwh in an STES station with a capacity of 200 MW with that of the 5-MW Crimean SES and found it to be one-eighth as much, whereas the cost of its electric power was seen to be one-fortieth as much.* Akhmedov believes that the combined station concept would make it possible not only to advance solar power engineering in favorable economic conditions but also to gain time for perfecting SES(43).

In June 1983 Vadim Maslov announced that a site for the STES had been proposed near the Talimardzhan Reservoir in Kashkadarinskaya Oblast in the Uzbek SSR(49). The preparation of the technical and economic specifications for the construction of the station, claimed to be the largest of its kind in the world, was to be completed by the end of 1983. The solar power module is to have a capacity of more than 100 MW, while the fuel-burning standby station will add another 200 MW to the plant's capacity. According to Maslov, such an STES is capable of generating up to 2 billion kwh of electrical energy a year and competing with conventional power stations from the standpoint of profitability(49, 50, 51).

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*In 1983 V. Maslov, director of the Central Asian branch of the All-Union Institute for the Designing of Nuclear, Thermal, and Electric Power Engineering Facilities (Atomteploelektroproyekt), estimated the per-kwh cost of power from the STES to be about one-fifth as much as for the SES(48).

The STES is to occupy an area of 10 km^2, most of which will be taken up by fields of heliostats. The turning of their mirrors will be controlled by a computer. Concentrated solar radiation will be reflected to a solar steam generator installed on a tower more than three hundred meters above the ground. The station's designers were said to be investigating the possibility of equipping it with several generating units that would have an overall capacity of 1,000 MW. Maslov also mentioned plans for building a system of heat accumulators—reinforced-concrete towers thirty meters high and seven meters in diameter—that would enable the station's solar module to operate for an additional four hours or more a day. During the day these accumulators would receive and store surplus heat that could be used to generate steam at night and in cloudy weather(49).

Each of the mirrors of the STES will measure 7m × 7m, and there will be 72,000 of them. Soviet scientists also are studying the possibility of building a series of small STES's near the Kyzylkum Desert's gas deposits; they would supply individual populated places and livestock farms(50).

Solar Space Stations. A more speculative approach to utilizing solar energy that has been studied by the Soviets, as well as by researchers in the United States, is via a solar power station in geosynchronous orbit. While such a power station seems feasible and has the advantage of steady insolation, its construction and use pose certain economic, social-legal, ecological, and other problems that must be resolved before serious development can begin(52, 53, 54). Academician G. Petrov of the Academy's Institute of Space Research said in a 1977 interview that a network of solar stations in near-earth orbit, using laser beams or microwave beams to transmit energy to earth, is a distant prospect but deserves very careful study(55).

Early in 1983 Professor V. Vanke of Moscow State University said that it was determined that the economically optimum capacity of such a station is between 5,000 and 10,000 MW. For a 5,000-MW station the overall area of the solar panels would have to be about 50 km^2. Vanke said the efficiency of reception and reconversion of microwave energy on earth could be as high as 90 percent if a high-efficiency transmitting antenna, 1 km in diameter, were used on the station. In estimating that commercial orbiting solar power stations could become a reality in twenty to thirty years, Vanke said it would have to be an international project(56).

Multijunction Solar Cells. Of particular concern in the field of solar energy is the high capital cost of solar energy conversion equipment relative to the amount of energy obtained. In this regard, one area of Soviet work that shows promise in developing more extensive use of solar energy to provide electric power is the use of matrix structures of vertical multijunction solar cells in "high-voltage photoconverters."

The leading personality in this work is D. S. Strebkov of the All-Union Scientific Research Institute of Current Sources(VNIIT). A 1973 article coauthored by A. P. Landsman, Strebkov, and V. A. Unishkov, apparently affiliated with ENIN, treats the question of the technical-economic potential of solar power plants using high-voltage photoconverters to generate power outputs of 1,000 MW or more(57). By use of solar concentrators and matrix solar cell structures, specific capacities of several hundred kw per square meter may be obtained with output of 1,000 MW or more and output voltages per unit area on the order of a million volts per square meter. Such high-voltage output should aid in simplifying the power-conditioning equipment required to transmit the solar electric power by high-voltage lines. VNIIT authors have continued to publish on high-voltage photoconverters, and Zhores Alferov, head of a laboratory of the Leningrad Physical-Technical Institute, announced in December 1982 the Soviet development of the world's first solar "battery" with a voltage of 32,000 volts(58).

Other Solar Programs. R&D efforts also have focused on the need for systems to store solar energy for periods when the sun is not shining and/or on the need for backup sources of heat or electric power for use during such periods. Ideally, storage techniques will be developed to the point where a solar energy system is self-sufficient. Finally, the Soviets are investigating opportunities for using solar energy through more efficient biomass processes(59).

Supporting Technologies. Many technologies are needed to support the successful utilization of solar energy. Perhaps the most important single technology is that of semiconductors. Much of the entire field of semiconductor technology is pertinent to solar cell development and manufacture. Important areas of development are techniques of doping the basic material; bonding to substrates and joining to contacts; surface films for atmospheric protection; manufacture of large-area, low-cost cells; deposition of thin-film semiconductors for flexible arrays and cost reduction; vertical-multijunction solar cells; and heterojunction solar cells. Heterojunction cells with conversion efficiencies of 25–26 percent have been developed, and the possibility of increasing efficiency to 45 percent reportedly has been demonstrated by the Soviets(58, 60).

Other important technologies for electric power production from solar energy include solar concentrator technology and power conditioning and switching. To be fully effective in concentrating available solar energy, a concentrator unit must be made to track the sun with a suitably timed drive system. Also, solar absorber technology can be improved considerably for efficient operation of solar thermal power systems.

A power-conditioning system for a solar power unit involves a considerable number of electrical components, most of which are made necessary by the need to produce AC power from a DC source. The design of available components can be improved for this particular application, making use of new technologies.

There is evidence that the Soviets are developing most of the supporting technologies cited here.

Key Organizations and Personalities

Nearly sixty Soviet research facilities have been identified in some way with the Soviet solar energy program. These represent diverse fields of science and technology.

Two of these facilities have played especially important roles in the Soviet solar energy research and development program. These are the All-Union Scientific Research Institute of Current Sources (VNIIT), and the State Power Engineering Institute imeni Krzhizhanovskiy (ENIN), both in Moscow. Of the two, VNIIT appears to be carrying out the larger volume of work on solar energy. However, it also appears that its primary emphases are on solar energy component development and basic research in solar energy conversion, while ENIN demonstrates an emphasis on terrestrial solar energy systems development.

VNIIT has a large number of researchers in the solar energy field, most of whom are concerned with the conversion of the sun's radiation into electrical current. Among these researchers, Arkadiy P. Landsman was the most prominent until his death in 1974. The director of VNIIT, N. S. Lidorenko, has assumed Landman's stance as a leading proponent of solar energy research, particularly photovoltaic applications.

A large Soviet effort directed toward the practical utilization of solar energy for supplying the energy needs of remote areas is centered in the southern republics, particularly the Uzbek SSR and the Turkmen SSR. Among other facilities in these republics, the Physical-Technical Institute imeni Starodubstev of the Uzbek Academy of Sciences, Tashkent, and the Physical-Technical Institute of the Turkmen Academy of Sciences, Ashkhabad, play central roles in the solar energy program. It is interesting that Soviet solar energy research stations and prototype power plants are located as far north as 45° north latitude (Mysovoye, in the Crimea).

The Soviet Union's Scientific Research Institute of Solar Energy (ISE) (the first in the USSR and the third in the world) was opened on January 5, 1979, at Ashkhabad, under the Turkmen Academy of Sciences. Its purpose is to develop and introduce into the national economy highly effective equipment using solar energy. The institute has a research site with numerous experimental industrial installations near Ashkhabad. At the time of its opening, ISE had a staff of about two hundred, including twenty-six candidates of science. The director of the institute is Doctor of Technical Sciences R. B. Bayramov, and the deputy director is Candidate of Technical Sciences A. D. Ushakova. One of the primary tasks of ISE is the development of autonomous, solar energy complexes for support of working groups in the desert(61, 62, 63, 64). The Turkmen Republic's first solar power station was put into operation at this institute early in 1983(51, 65).

A Turkmen branch of VNIIT is also located near Ashkhabad, in the village of Bekrova. This branch, directed by B. Bazarov, belongs to the "Kvant" Science-Production Association (NPO). The branch plans to build a commercial pilot solar power station in Bekrova, which will serve as a research and test facility. It is claimed that VNIIT scientists have developed unique production methods for solar cells that have made it possible to reduce their cost by 75 percent. A production shop using these methods was expected to begin operation in Ashkhabad in 1983(66).

In May 1980 it was announced that ISE had established a new NPO known as the "Solntse" (Sun) Science-Production Association of the Turkmen Academy of Sciences. Solntse is directed by R. B. Bayramov, the head of ISE, and is located in the settlement of Bekrova, near Ashkhabad. The association includes ISE and twenty-five laboratories and is pursuing the development of various industrial and commercial applications of solar energy(48, 63, 67, 68, 69).

A second NPO—the "Kvant" Science-Production Association—is located in Yerevan. In May 1980 it was announced that specialists of this NPO had developed an improved tracking system for solar reflectors used in small power plants(70). It was reported in 1983 that the Kvant NPO, under the direction of VNIIT director N. S. Lidorenko, had constructed, for testing, an electric-drive tractor with continuous solar-cell battery charging(71).

With so many institutes involved in R&D on solar energy, it has become necessary for the USSR to establish mechanisms to coordinate work and prevent excessive duplication of effort. One coordinating organization is the USSR Academy's Scientific Council for the Problem "Finding New Ways to Use Solar Power"(59). A second coordinating center is the Kharkov Polytechnic Institute imeni Lenin, which has been given the assignment of coordinating the research of fourteen institutes of higher learning on thin-film photovoltaic cells(72). Finally, the Turkmen SSR Ministry of Higher and Specialized Secondary Education has been designated the head organization for the problem "Solar Power Engineering." This ministry is responsible for coordinating the work of all Soviet higher schools on this problem(73).

Key organizations and personalities engaged in solar energy are listed in table 17.

Relationships and Rivalries. ENIN is carrying out research and development efforts on solar energy that appear to be steadily increasing in volume. Some former VNIIT solar energy personalities are now on the staff of the Krzhizhanovskiy Institute (e.g., Tarnizhevskiy) and at the other, more remote, facilities. These moves may have been precipitated by the death of VNIIT's A. P. Landsman and subsequent reorganization of its solar energy department. The researchers of VNIIT and ENIN do cooperate in their work and publications, however.

Evaluation

Significance of the Effort. R&D manpower assigned to the Soviet solar energy program appears to be large, compared with that assigned to

Table 17 Key Organizations and Personalities Engaged in Solar Energy R&D

Scientific Council for the Problem "Finding New Ways to Use Solar Power," USSR Academy of Sciences
A. Kokorin, scientific secretary

Section on Thermodynamic Conversion of Solar Energy of the Scientific Council on the Problem of Utilizing Renewable Sources of Energy, GKNT(47)

All-Union Scientific Research Institute of Current Sources (VNIIT), Minpribor, Moscow
N. S. Lidorenko, director
T. M. Golovner
A. M. Vasilyev
G. F. Muchnik
M. B. Kagan
M. M. Koltun
D. S. Strebkov

State Power Engineering Institute imeni Krzhizhanovskiy (ENIN), Minenergo, Moscow
B. V. Tarnizhevskiy
Yu. N. Malevskiy
D. I. Teplyakov
R. B. Akhmedov

Kharkov Polytechnic Institute imeni Lenin, MVSSO Ukrainian SSR(72)

Institute of Semiconductors, USSR Academy of Sciences, Leningrad

Scientific Research Institute of Physics, Moscow State University MVSSO SSSR

Physical-Technical Institute, Uzbek Academy of Sciences, Tashkent

Physical-Technical Institute imeni Ioffe, USSR Academy of Sciences, Leningrad

All-Union Scientific Research Institute of Electromechanics, Yerevan

Physical-Technical Institute, Turkmen Academy of Sciences, Ashkhabad

Crimean Heliotechnical Laboratory of the Institute of Problems of Materials Science, Ukrainian Academy of Sciences

Scientific Research Institute of Solar Energy (ISE), Turkmen Academy of Sciences, Ashkhabad
R. B. Bayramov, director

Institute of Photosynthesis(59)

Solar Power Engineering Commission of the All-Union Council of Scientific-Technical Societies(74)

Table 17 (continued)

"Solntse" Science-Production Association, Turkmen Academy of Sciences, Ashkhabad
"Kvant" Science-Production Association, Yerevan

other direct energy conversion programs. It was reported in 1972 that the total manpower being applied in the terrestrial solar energy field ranged from 500 to 600, of which 150 to 200 were professionals(27).

The Soviets have been relatively prolific in the publication of technical articles on solar energy. One journal, *Geliotekhnika*, is devoted entirely to disseminating research results in the field, and numerous articles have been published in other journals dealing with energy conversion.

While the Soviets have been quick to experiment with solar energy conversion hardware for terrestrial application, the power levels achieved have been generally of an order of magnitude less than for equipment of comparable type built in the United States. However, this situation appears to be changing, with Soviet power levels becoming more comparable to those in the United States.

According to N. S. Lidorenko, director of VNIIT, the Soviets consider the development of solar power engineering important enough to have established within the CMEA countries a coordination plan for joint work on utilization of solar energy(75).

Economic Considerations. As noted earlier, the technical feasibility of most of the major solar applications has been demonstrated, and attention has turned to study and improvement of the economics of solar energy. According to Soviet sources, some solar installations, such as solar collectors making use of the sun by thermal engineering methods, can be profitably applied as far north as 56° north latitude(59).* However, these claims appear to be yet another example of the notoriously poor economic analyses that frequently emanate from special interest groups in the USSR. It seems doubtful that solar energy will find much application outside of a limited number of southern rural areas of the USSR unless it becomes more economically competitive. Methods of converting sunlight to electric power will have to be made more efficient, capital costs must be reduced, and practical storage means will need to be developed. All of these problems are being investigated by the Soviets. In the area of thin-film photovoltaic cells, researchers are seeking to reduce the production cost of cells by a factor of at least ten(66).

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*This latitude takes in Minsk, Moscow, Kazan, Novosibirsk, and Irkutsk.

An important step in reducing the cost of solar equipment will be the move to mass production of such equipment. According to a 1977 article in *Nedelya,* the opening of the first Soviet manufacturing facility for the production of solar energy apparatus (in the Bukhara Oblast of the Uzbek SSR) was expected to decrease equipment costs considerably(76).

The Kvant NPO has been working to lower the cost of silicon solar cells as well as to further the development of solar metallurgical furnaces for rapid melting and zone melting(68, 77, 78). According to A. Vartanyan, head of the Yerevan solar-proving facility of NPO Kvant, an experimental solar furnace with a 1.5-meter mirror has been under development to synthesize beta alumina by means of a very rapid thermal shock. The exceptionally pure product will aid in the development of advanced batteries to power electric motor vehicles(78, 79). The Yerevan Research Center for the Utilization of Solar Energy, attached to Kvant, has one of the USSR's 120 experimental solar electric power stations(77). The Kvant NPO has also developed a new parabolocylindrical solar energy concentrator that is said to be simple, reliable, and comparatively inexpensive. The new concentrator converts more than 50 percent of incident solar energy into heat and can be mass-produced with special equipment(80).

In spite of these achievements, Soviet NPOs were criticized early in 1983 by Professor K. Taksir, deputy chairman of the USSR Academy of Sciences' Scientific Council on Economic Problems of Scientific and Technical Progress. Taksir pointed out that, in general, the NPOs are poorly organized for their function and that planning of their efforts is improperly carried out. He indicated that there has been too much emphasis on profitable production techniques and not enough on producibility of new products showing technological advantages(81).

Time Frame for Development. R&D on solar energy has been in progress in the Soviet Union for the past two decades but accelerated during the 1970s. By 1977 more than sixty terrestrial solar power devices were reported to be in operation in the USSR(82), and the first solar equipment factory was about ready to open(76). The first multimegawatt Soviet solar electric power station, the SES-5, was scheduled to become operational by 1985(43), and a 300-MW solar and fuel power station (STES) has been designed, with construction apparently to have begun in 1984(49).

According to S. N. Yatrov, estimates by Gosplan's VNIIKTEP indicate that the contribution of solar energy to the national economy during the 1980s could reach several million tons of standard fuel(83). Other projections indicate that a significant fraction of energy requirements will be met by the use of solar energy by the year 2000, perhaps 4 to 10 percent. In the long run, Soviet experts estimate that solar energy will be capable of supplying 30 to 40 percent of the energy needs of humanity(84).

Geothermal Energy

Description of Programs

In conjunction with plans for the economic development of the Soviet Union during the Eleventh Five-Year Plan and the period to 1990, the Twenty-sixth Congress of the Communist Party published a main direction calling for an increase in the scale of use of renewable energy sources(85). One such source is geothermal energy.

Soviet geothermal resources are being developed with a number of applications in mind. A 1977 article(86) gave the following breakdown of current usage (percentage of thermal water extracted): heat for agricultural production, 25 percent; heat for communal living, medical, and industrial consumers, 62 percent; production of electric power, 13 percent. Potential applications depend on the temperature of the waters available: water temperatures above 90°C are considered suitable for generating electricity, 50°C or more is needed for district heating, and at least 40°C water is wanted for hotbeds(85).

Although new installations will frequently include a number of applications in order to gain the benefits of "cascading" from high-temperature to low-temperature applications, specific applications are discussed separately below.

Production of Electric Power. Since 1967 the Soviet Union has operated a geothermal electric power plant (GEOTES) at Pauzhetka on the Kamchatka Peninsula using natural hot water and steam deposits that are only 300 to 500 meters below the surface(87). Although this plant had a rated power output of 5.0 MW, it experienced difficulties and operated at only 3.5 MW(88). However, in July 1977 it was reported that seven new wells had been drilled for the power plant, and a 1980 report indicated that the addition of a new turbine would double the plant's capacity by the end of 1980(89, 90). Apparently the new capacity (referred to as the plant's "second phase") came on line in early 1981(85). In mid-1983 the Pauzhetka GEOTES was reported to have a capacity of 11 MW(23). Reserves available at the site would permit an expansion of the plant's capacity to 25MW, but there is no evidence that such a large expansion is imminent(91).*

A second power plant on Kamchatka was located at Paratunka and operated from 1968 until 1975(92, 93). This was a binary-cycle system in which thermal water at 80°C was used to evaporate Freon-12 (which boils at 29.8°C). The gaseous Freon was used to turn a turbine and then returned through the closed system to the heat exchanger. This system was worked out by the Institute of Thermophysics at Novosibirsk, VNIIKholodmash (expansion unknown), and other organizations and was built to further research on low-temperature geothermal power generation(93). The system originally was designed to use 90°C water and to have a capacity of 750 kw, but the water proved to be cooler (80°C), and normal operating levels were approximately 400 kw. The Paratunka plant was closed in 1975 after having reportedly achieved its R&D goals(92).

Several new power plants have been discussed. A 12-MW power plant reportedly is to be built near Yuzhno-Kurilsk on Kunashir Island in the southern Kurile Islands(18). Mangushev of VNIIKTEP has spoken of proposals to build a 50- to 70-MW plant in the vicinity of the Pauzhetka power plant (to be called the Nizhnekoshyelev Geothermal Station)(94).

There were also reports in 1975 of plans to build a prototype plant utilizing the magma deposits associated with the Avachinsk Volcano near Petropavlovsk-Kamchatskiy. Inclined wells would be drilled about 4 km from the volcano and explosions set off underground to create a large natural boiler. A nearby creek was to be diverted into the chamber where it would be subjected to temperatures of 600°C, transformed into steam, and drawn off to power a turbine. The power plant reportedly would have a capacity of 300 MW(87).

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*A later source refers to the possibility of expanding to only 17 MW(90).

There has been little recent discussion of the Avachinsk project, but in 1978 plans were announced for the construction of a power plant on the slopes of the Mutnovskiy Volcano (also near Petropavlovsk-Kamchatskiy)(95). Recent reports call for the Mutnovskaya GEOTES to have a capacity of 50 MW when it begins operation (before the end of 1988) and an eventual capacity of 150–200MW(23, 50).

In contrast to these efforts, which have tapped geothermal resources within 500 meters of the earth's surface, the Soviets now are beginning work on installations that would utilize geothermal resources located at depths of up to 4,000 meters. By mid-1983 construction of pilot industrial installations had begun in Stavropol Kray, in Dagestan, and in the Transcarpathian area(50). Initially, these pilot installations would have capacities of 10 MW, but later they could be expanded to 100 MW or more(23). Successful exploitation of such deep deposits would open up a vast energy resource with the potential to support 150,000 MW of power-generating capacity(50). (In 1983 the USSR had a total of 293,558 MW of power capacity(34).)

As of the end of February 1982, the first of six geothermal wells had been drilled at the Stavropol site in Northern Kazakhstan(96).

Heat for Agricultural Production. Agricultural application of thermal waters is not as exciting to the general public as is thermal power generation, but in recent years in the Soviet Union it has consumed about twice as much thermal water(86). Greenhouses heated by thermal waters have been in use for a number of years in the Caucasus, on the Kamchatka Peninsula, and in the Buryat ASSR(18, 90, 97). According to one source, thermal water supplies on Kamchatka are sufficient to provide 8 to 10 million people with fresh vegetables if developed properly. Geothermal waters also are being used for fish breeding and wool washing in Siberia(18).

At some sites, such as Mostovskiy Rayon in Krasnodarskiy Kray (northwest Caucausus), a systematic attempt has been made to arrange a sequence of agricultural applications so that cascading benefits can be achieved. There, geothermal waters first are used to heat greenhouses, and then, after cooling to 40–50°C, the waters are piped to buildings housing livestock (poultry, hogs, and cows). Following utilization in feed preparation, the geothermal waters (now cooled to 25–30°C) are piped into fish ponds to accelerate the growth of fish(98).

Residential Space Heating and Other Applications. Most of the other fields of application of geothermal energy make direct use of the heat from geothermal sources. District heating is now being supplied to a number of urban residents in the Georgian cities of Tbilisi and Zugdidi; in Makhachkala, Izberbash, and Kizlyar (all in the Dagestan ASSR); in Maykop and Tyumen; on the Kamchatka Peninsula; and in other areas of the Soviet Union(85, 86, 95). Consideration is being given to heating Groznyy, a city of 400,000 in the Caucasus, with geothermal energy(99). Thermal waters are being used for waterflooding of reservoirs containing high viscosity petroleums in the Kazakh SSR and in Western Siberia(97, 100), to assist in year-round operation of placer mines in Chukotka(94), and as sources of iodide and bromide(97). Industrial applications have been discussed, but little action has been taken in this area to date beyond some small-scale applications in woodworking and production of concrete(98).

Key Organizations and Personalities

Many organizations have been involved in activities that have contributed to the development of the geothermal energy resources of the USSR. But until 1977 there was no single central organization that planned or supervised the development of these resources. As a result, there were frequent instances of confusion, duplication of effort, and failure to take necessary actions. An attempt was made in 1977 to reorganize geothermal activities, but it is not clear that this reorganization will entirely eliminate those problems(92). The following discussion attempts a "top-down" review of the major organizations involved in geothermal activities.

Since 1977 responsibility for central planning of geothermal resource development has rested with the State Committee for Science and Technology (GKNT) and, in particular, with the Geothermal Branch of the Section on Renewable Energy Sources of the GKNT's Committee on Power and Electrification(92). Based on the discussion of "main directions" presented in chapter 2 of this book, it can be assumed that in carrying out its planning role the GKNT interacts with the USSR Academy of Sciences and Gosplan USSR. Specific units within these organizations that have been identified are the Academy's Scientific Council on Geothermal Studies(93)* and Gosplan's Institute for Comprehensive Fuel and Energy Problems (VNIIKTEP), which has a geothermal program headed by Kyamil Mangushev(94).

In theory, the Ministry of the Gas Industry (Mingazprom) is the lead organization in the actual development of geothermal sites, but it has been criticized for ineffective leadership(89, 97). In addition, key activities are under the control of other organizations: the Ministry of Geology is responsible for prospecting for geothermal sites and for exploratory drilling; the Ministry of the Gas Industry drills production wells and develops the capability for extracting thermal waters; the Ministry of Power and Electrification is charged with the design, construction, and operation of geothermal power stations(92); and the Ministry of Agriculture is to organize greenhouse combines heated by geothermal waters(97).

Within Mingazprom there are many organizations involved in geothermal activities. The production and sale of thermal waters have been carried out by four field administrations serving Dagestan, Georgia, Checheno-Ingushetiya, and Kamchatka(97). R&D efforts within the ministry are led by the All-Union Scientific Research Institute of Natural Gas (VNIIGaz) and the North Caucasus Scientific Research Institute of Natural Gas (SEVKAVNIIGaz), with assistance from several science-production associations and lesser institutes(86).

Geothermal R&D also is conducted outside Mingazprom at a number of sites. The Institute of Thermophysics of the Siberian Division of the USSR Academy of Sciences has played an important role in the development of binary-cycle geothermal power stations. Other institutes of the USSR Academy have contributed through geochemical studies of potential geothermal sites, estimation of the geothermal potential of Siberia and other parts of the Soviet Union, mapping of temperature profiles of the earth, and the measurement of thermal flows(93). Other important institutes include the Leningrad Mining Institute (geothermal mapping; artificial recirculation systems)(94), the Institute of Technical Thermophysics of the Ukrainian Academy of Sciences (artificial recirculation systems), and the

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*In 1961 the presidium of the USSR Academy organized a Commission on Hydrogeology and Geothermics under its Division of Geological and Geographic Sciences. In 1964 this commission was transformed into the Scientific Council on Geothermal Studies(93).

State Power Engineering Institute imeni Krzhizhanovskiy (ENIN) (hot-rock geothermal development)(92).

Strong local support for geothermal energy exists in certain areas likely to benefit from it. As an example, Dagestan's Gosplan has taken a strong interest in geothermal developments in that autonomous republic and has sought to promote and coordinate geothermal activities through its Council for the Control and Utilization of Renewable Energy Sources(89).

The development of geothermal resources is strongly supported by certain prominent persons, including A. Gadzhiyev (chairman of Dagestan's Gosplan), I. M. Dvorov (deputy chairman of the Scientific Council on Geothermal Research of the USSR Academy of Sciences), and Kyamil Mangushev (head of the geothermal program at the Institute for Comprehensive Fuel and Energy Problems of Gosplan USSR). Of course, those persons all have vested interests in geothermal power and would be expected to support it.

More significant is the support expressed by S. N. Yatrov, the director of VNIIKTEP and a person who should play an important role in formulating the energy views of Gosplan USSR. In a 1978 article Yatrov displayed a generally favorable attitude toward geothermal energy as a source of both heat and electric power. He concluded his article with the statement: "The harnessing of subterranean heat is no longer a science-fiction dream. It is a practical task"(101).

On the other hand, V. A. Kirillin, then the chairmen of the GKNT, was more cautious in his assessment of geothermal energy, at least as a source for electric power generation. In a 1975 article he indicated that there are no solutions that "are satisfactory from the technical economic viewpoint . . . for the use of geothermal energy on a large scale for the needs of the power industry. The main difficulty is the organization of heat exchange on a large scale at a great depth"(102).

Table 18 presents a list of prominent organizations and individuals involved in Soviet geothermal work.

Evaluation of Geothermal Programs

The Economics of Geothermal Energy. Geothermal energy is more economical than existing energy sources *in certain regions of the USSR.* As an example, it was reported in 1981 that the 5-MW

Table 18 Key Organizations and Personalities Involved in Geothermal Energy Research

All-Union Scientific Research Institute for Comprehensive Fuel and Energy Problems (VNIIKTEP), attached to Gosplan USSR
  K. Mangushev

USSR Ministry of Gas Industry

USSR Ministry of Geology(88)

USSR Ministry of Power and Electrification

Council for the Control and Utilization of Renewable Energy Sources (under Dagestan's Gosplan)
  A. Gadzhiyev

All-Union Planning, Surveying and Scientific Research Institute imeni S. Ya. Zhuk (Gidroproyekt), Minenergo, Moscow
  S. I. Milkovitskiy

Leningrad Mining Institute, MVSSO RSFSR
  Yu. Dyadkin(105)

Institute of Technical Thermal Physics, Ukrainian Academy of Sciences, Kiev

Institute of Volcanology, USSR Academy of Sciences, Petropavlovsk-Kamchatskiy(88)

All-Union State Institute for the Planning of Electrical Equipment for Thermal Engineering Structures (Teploelektroproyekt)(106)

Institute of Geothermal Problems, Dagestan Branch of USSR Academy of Sciences(85, 106)

State Power Engineering Institute imeni Krzhizhanovskiy (ENIN), Minenergo, Moscow(92,106)

Groznyy Oil Institute, MVSSO RSFSR
  G. Sukharev(99)

Dagestan Multipurpose Geological Expedition

Pauzhetka Electric Power Plant on Kamchatka produced electricity at a cost (*sebestoimost*) of up to 3.9 kopecks per kwh vs. 15–17 kopecks at diesel-fired power plants in the region; however, this is 50 percent higher than the cost from a 150-MW conventional thermal power plant, a more typical alternative(18, 85).* Unless geothermal power plants can be made more efficient than this, they will probably be built only in remote areas with population bases that are too small to justify large conventional power plants or where the delivered cost of fossil fuels is exceptionally high. It is claimed that the Mutnovskaya GEOTES will produce electricity more cheaply than would a (presumably comparably sized) thermal or nuclear power station in the same location, but no estimates of costs were presented(50). Given the modest size of the planned GEOTES (50 MW at first), costs of electricity may be relatively high.

The situation is more favorable when one considers district heating applications. The cost per Gcal of heat with geothermal sources is reported to be 1.5 to 2 rubles in the Caucasus and 2 to 2.5 rubles on Kamchatka—about one-third to one-half the cost of heat from thermal power plants or large boiler operations(86). For cities and mines located above the Arctic Circle, it is estimated that heat from geothermal sources will cost only one-fifth to one-tenth as much as delivered fuel from traditional sources(105).

In the case of greenhouse operations it is said that vegetables grown in greenhouses heated by geothermal sources cost 20 to 25 rubles per quintal** vs. 67.3 rubles if heat is obtained from normal sources(86). Expenditures for construction reportedly can be recovered in only two to three years, implying a very high rate of return(85). (Of course, most vegetables in the Soviet Union are not grown in greenhouses.)

In summary, geothermal electric power is most attractive from an economic point of view in regions where electricity is expensive. Unless the cost of generating electricity from geothermal heat can be reduced, this application may be confined to a small number of local areas. District heating with geothermal energy is more competitive, though, and is likely to find wider geographic application.

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*Further analysis of the Pauzhetka plant is possible, based on information published in 1980(90). That source indicated that to date the plant had generated a total of 165 million kwh of electricity, saving 67,000 m.t.s.f. from traditional sources. Dividing the latter figure by the former implies that the standard of comparison is a plant that requires almost 409 grams of standard fuel per kwh of electricity. By contrast, the national average rate of transformation was below 367 g/kwh throughout the 1970s(103) and only three of the fifty-two regional power systems tabulated by Dienes and Shabad had such unfavorable transformation rates (figures for 1974)(104). The calculated transformation rate (409 g.s.f./kwh) is about 12 percent higher than the average rate for 150 MW thermal power units in 1975—366.4 g(103).

**A quintal is a metric unit of weight equal to 220.46 U.S. pounds.

Significance of the Effort. Geothermal resources have been developed at a rapid rate but are not yet having a significant impact on the total Soviet energy picture and do not seem likely to have such an impact in the immediate future.

Representatives of Mingazprom report that the extraction of thermal water increased more than twenty-six times during the period 1967–77. During the Ninth Five-Year Plan (1971–75), 78 million m^3 of thermal water were extracted, while the Tenth Five-Year Plan was to see the total expand by 144 percent, to 190 million m^3. Figures for more recent years have reflected these high rates of planned growth: extraction in 1976 reached 26.4 million m^3 and was scheduled to expand by 21 percent, to 32 million m^3, in 1977(86). A February 1979 article indicated that the annual rate was then about 35 million m^3 of thermal water and 270,000 tons of steam(83) while a July 1981 report gave annual rates of 40 million m^3 and 300,000 tons, respectively(106).

By the end of the Ninth Five-Year Plan, 145 wells were being operated by the four field administrations of Mingazprom and 19 more were to be added in 1977. Drilling during the Tenth Five-Year Plan was to total 240,000 meters(86). In mid-1981 170 wells were operating in 36 fields around the country(106).

Whether these rates of growth are to be considered satisfactory is a matter of one's expectations. I. M. Dvorov of the USSR Academy of Sciences and A. Gadzhiyev of Dagestan's Gosplan have been very critical of the progress of geothermal energy(89, 97), while representatives of Mingazprom have (understandably) been more upbeat(86).

In any case, it is unlikely that geothermal resources will have a significant impact on total supplies of energy in the Soviet Union in the foreseeable future. Extraction during the Ninth Five-Year Plan (78 million m^3 of thermal water and 1.1 million tons of steam) was equal to only 800,000 m.t. of standard fuel, about one-hundredth of 1 percent of total fuel production during that five-year period (7,127.7 million tons of standard fuel)(86, 107, 108).

In December 1978 Yatrov indicated that in the "near future" the Soviet Union could gain from geothermal sources new energy resources equivalent to 5–10 million m.t. of standard fuel(101). Such an increase would represent a substantial expansion of geothermal activities but still would leave this source accounting for less than 1 percent of total annual Soviet energy production(107).* Even with strong political support, geothermal energy is likely to be of little more than local significance as an energy source over the next several decades. At the local level, however, it will have an impact. As of mid-1981, thermal water was supplying the heating and hot-water needs of half the population of Izberbash and Kizlyar and 12 percent of the residents of Makhachkala(85). By mid-1983 about 60,000 people in Dagestan were using geothermal waters, and over 160,000 m^2 of buildings were being heated by geothermal means. As a result of these efforts, it has been possible to shut down twenty-two boilers and achieve annual savings of 55,000 m.t.s.f.(23).

Institutional Barriers. As in many other areas of Soviet science and technology, the development and implementation of geothermal technology is being held back by institutional and systemic barriers. Work on designing and costing installations for extracting thermal waters cannot proceed without the permission of the USSR State Commission on Mineral Resources. The Ministry of the Gas Industry, which is in charge of most Soviet geothermal production work, is preoccupied with the problems of developing natural gas and is not pushing needed geological prospecting efforts in potential geothermal areas(106). Many potential sources of geothermal water are under the administrative control of organizations for which geothermal work is a peripheral activity (e.g., Azneft—the State Association of the Azerbaydzhan Oil Industry)(85). Official prices for geothermal water are set too low (6 kopecks/m^3) and do not reflect the energy value of the water. Little support work has been carried out on water treatment facilities or heat exchangers(106).

Conclusions. Geothermal energy sources will be developed further in the Soviet Union over the next few decades but will likely be confined to selective applications and to a limited number of geographic locations. Geothermal waters probably will be used increasingly for heating residential areas and greenhouses, and in placer mines and in a limited number of other productive activities that do not require high-temperature heat sources. The distance of geothermal waters from the surface probably will be an important factor in such applications.

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*Total fuel production for the Soviet Union in 1983 was equal to 2,036.2 million tons of standard fuel. It is interesting to note that after such a dramatic expansion geothermal sources of energy still would be contributing less than firewood did in 1983 (23.1 million tons)(34).

Application of geothermal sources for electric power generation is much more problematic at this time. Such power plants now are competitive in remote areas served by small-scale diesel plants but are much less attractive in areas that can support large conventional thermal power plants. Research is under way to develop binary-cycle plants suitable for use with low-temperature sources and to develop volcanic magma deposits. However, such activities seem likely to remain experimental in nature for the next decade.

Geothermal sources are unlikely to account for as much as 1 percent of total Soviet energy production before 1990.

Underground Gasification of Coal

Underground gasification of coal (UGC) is a process for exploiting the energy potential of underground coal by converting it into a gas while still buried and raising the gas to the surface for use as a fuel. The seam of coal is ignited and is fed with normal air or oxygen-enriched air that passes down through bore holes. A low-BTU gas is produced and passed to the surface for use as a source of process heat, as a fuel for electric power plants, or as a chemical feedstock.

UGC is most economical in cases where coal seams are too deep to justify strip mining and are too small, low-grade, or steeply sloped to make conventional underground mining techniques reasonable.

History of Soviet R&D

Underground gasification of coal has a long history in the USSR. D. I. Mendeleyev, the famous Russian chemist, suggested the idea as early as 1888(109). Lenin became interested in the concept and provided official support that led to field experiments beginning in 1933(110). By 1936 approximately 1,500 workers were employed in UGC(111).

Soviet R&D efforts were disrupted by World War II, which saw the Germans destroy installations in the Donets Basin and at Tula(111). But these facilities soon were repaired, and new ones were opened during the 1950s. From 1945 to 1958 a total of approximately 41.7

million new rubles was invested in underground gasification of coal(112).

As of 1961, there were seven commercial or experimental "podzemgaz" (underground gasification) stations in existence: Angren P.S. (southeast of Tashkent), Shatsk P.S. (near Tula), Yuzhno-Abinsk P.S. (in the Kuznetsk Basin), Kamensk Industrial Experimental P.S. (Rostov Oblast), Lisichansk P.S. (in the Donets Basin), Podmoskovnaya Podzemgaz Station (near Moscow), and Sinelnikovo P.S. (Dnepropetrovsk Oblast). In addition, an experimental site for underground gasification of oil shales was under construction near Kivioli in the Estonian SSR(113)

Interest in UGC continued in the early 1960s but then began to decline because of (1) technical problems with the Soviet UGC processes, (2) growing doubts about the economics of UGC, and (3) large discoveries of oil and natural gas that provided a cheaper, more convenient, and less technologically risky alternative to UGC.

Technical and Economic Problems

The concept of UGC is fairly straightforward, but many problems arise in trying to develop a process that is technically efficient, environmentally acceptable, and economical.

From a resource point of view, numerous solid fuels could be considered for underground gasification, and the characteristics of the fuel in question must be considered in designing a UGC system. The Soviets have experimented with a variety of solid fuels, including bituminous coals (with various volatile contents), lignites, and oil shale(114).

On the technical side there are a number of design variants that can be considered. The passages through which natural or oxygen-enriched air is injected and gas is removed can be linked by relying on natural permeability of the coal seam, or by enhancing permeability by means of explosive charges, directional drilling, countercurrent combustion, electrolinking, or hydrofracturing. Directional drilling is highly developed in the Soviet Union but has not been mastered to the same degree in the West. Electrolinking—a process by which an electric current is passed through the coal seam to char a channel—is feasible but is difficult to control because of anomalies in the coal seam. Hydrofracturing—a technique in which water is pumped into the seam under pressure to open cracks—also is difficult to control. Ideally, these techniques will provide a direct link between input and output wells. However, they also may open fissures in other directions, allowing injected air and generated gas to migrate away from the zone of planned combustion and transmission. In some cases the gasified product (which contains carbon monoxide) may find its way to the surface of the ground, creating health and environmental problems.

Natural air is commonly injected, but experiments also have been conducted in which steam, oxygen, or hydrogen has been added to change the dynamics of the gasification process or raise the thermal value of the gas obtained. However, such additions cannot be carried out in an indiscriminant manner. As examples, moisture remaining in the produced gas reduces the thermal value of the latter, while overzealous use of oxygen may result in conversion of carbon monoxide into carbon dioxide, thereby reducing the thermal value of one of the important constituents of the gas produced.

Without going into further technical details, it should be evident that there are many technical variants on the basic process of underground gasification from which engineers must select in order to optimize design elements.

A common problem with many subcomponents of the UGC process is the difficulty of knowing and controlling what is happening. Unlike surface gasification, where the process occurs in an environment that is largely manmade and controllable, UGC is carried out in nature's domain where unknown anomalies in the coal seam and in the surrounding earth can have important and unpredictable effects on the process.

The numerous problems encountered in attempts to develop workable and efficient designs for UGC have given rise to a debate in the Soviet technical literature about the economics of UGC. One of the strongest attacks on the economic rationality of UGC is contained in a book by Z. F. Chukhanov of ENIN, which was published in 1961. In that study, Chukhanov argued that figures of VNII Podzemgaz (discussed below) indicated that after allowing for incomplete combustion, loss of gas in movement to the surface, and consumption by the *podzemgaz* station itself, only 13 percent of the potential heat of the commercial reserves of the coal seam would reach the consumer of the gas; by comparison, he estimated that 60 to 65 percent of the potential heat would reach the consumer if traditional shaft mining were employed. In the specific case of the Podmoskovnaya P.S. he argued that out of 6.5 million m.t. of the commercial coal reserves consumed by the station by 1956, only 0.7 million m.t. were transformed into gas and only about 300,000 m.t. reached the consumers of the gas—less than 5 percent of the original reserves. Chukhanov estimated that the fuel provided by the Podmoskovnaya P.S. cost 3 to 3.5 times as much as that available from coal mined by traditional means in the Moscow area(115).

Supporters of UGC replied to Chukhanov's calculations with figures of their own. In a 1968 article Lavrov, Nusinov, and Semenenko, three experts on underground gasification of coal, presented figures on the Angren P.S. that put the technology in a more favorable light(116). Technical portions of the article make it clear that many factors influence the UGC process and hence that conditions must be adjusted to something approaching a commercial optimum before a judgment on the technical and economic efficiency of the process can be on firm ground. It is noted, for example, that there is an inverse relationship between the moisture content of the gas produced and the thermal value of the gas and that there are economies of scale in the production of gas. On the latter point, the authors note that the cost per ton of standard fuel produced at the Angren P.S. in 1965, when production was at a high level (1,410 million m^3 of gas), was only 16 rubles/m.t.s.f.—lower than the cost from most underground coal mines in Central Asia where costs ranged from 18.9 to 26.6 rubles/m.t.s.f.(116).

In a 1981 article Arens and Petrenko argue that *podzemgaz* stations can be built two and a half to three times faster than an equal-capacity shaft mine and that the capital investment required for the P.S. is two times less(110).*

It is clear from this debate that in the 1960s the economics of UGC became a source of controversy in the USSR, but it is difficult for a Western economist to judge the merits of the various arguments put forward in the debate because the participants talk past one another in many cases, concentrate on measures that are of limited relevance, or use economic concepts that are unacceptable in the West.

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*The construction time advantage is not an insignificant point in the Soviet Union where construction times for shaft mines can be as long as a decade.

Chukhanov's argument is phrased largely in terms of the percentage of thermal value of coal reaching the consumer of the gas, while Lavrov, Nusinov, and Semenenko concentrate, more properly, on the cost per ton of standard fuel.

When the parties to this controversy do discuss costs, both sides use the Soviet concept of *sebestoimost,* a measure that includes direct costs as well as depreciation but not interest charges on capital. Most Western economists would prefer to see the arguments phrased in terms of the Soviet cost concept *privedennyye zatraty,* which adds interest charges to *sebestoimost.* Unfortunately, the broader measure is seldom employed. The omission of interest charges distorts comparisons in which the capital intensities of competing projects differ, making the more capital-intensive project look better than it should. One must also wonder how the coal in the ground is valued in these calculations and what assumptions are made about coal left in the ground. We have seen no explanation of these parts of the measurement process.

Looking back, it is likely that the growing availability of inexpensive crude oil and natural gas overwhelmed the subtleties of these calculations, making disputes about the relative economics of shaft mining and underground gasification of coal moot. If gaseous fuel were needed, it was clear that natural gas was the logical source for decades to come. In addition to its immediate cost advantage, there were many fewer technological uncertainties associated with natural gas than with gas produced by UGC.

Current Status of the Program

In recent years a maximum of three Soviet *podzemgaz* stations have been in operation (Shatsk,* Angren, and Yuzhno-Abinsk), and combined annual production of gas has been about 1.5 billion m^3, little more than in 1965(117, 120). Technical indicators for the three stations are shown in table 19 (information published in 1976).

In February 1982 it was reported that only the Angren and Yuzhno-Abinsk stations were still in service(114). Gas from the Angren station is sent to the Angren state district electric power station, while

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*Some say the operating P.S. near Moscow was the Shatsk P.S.(109, 117), while others say that the Podmoskovnaya P.S. still was operating(118). The confusion may arise because the Shatsk P.S. is located in the Moscow (*Podmoskovnyy*) Basin(119).

Table 19 Technical Indicators of Soviet Underground Coal Gasification Stations

Indicator	Shatsk or Podmoskovnaya P.S.*	Angren P.S.	Yuzhno-Abinsk P.S.
Type of coal	brown	brown	SS and GZh
Depth, m	40–60	110–150	250
Thickness of seam, m	to 2	to 20	8–23
Slope	horizontal	up to 15°	45–70°
Thermal value of gas, kcal/nm^3	700–800	800–850	1,050–1,100
Gas composition, %			
CO_2	17	19	11.8
CO	5.5	5.6	13.4
H_2	13.5	15.2	13.0
CH_4	1.6	2.5	3.6
C_nH_m	0.2	0.2	0.1
O_2	0.5	0.5	0.2
H_2S	1.0	0.4	0.01
N_2	60.7	56.1	57.9

*Altshuler(118) calls this the Podmoskovnaya P.S., but other evidence suggests that it is the Shatsk P.S. In any case, the technical characteristics of the two stations are very similar except that the Shatsk station uses coal with a lower ash content and produces gas with a somewhat lower heating value than is the case with the Podmoskovnaya P.S.(114).

Source: Reference(118)

gas from the Yuzhno-Abinsk station is used for heating purposes at fourteen industrial enterprises in the town of Kiselevsk(114).

The increased availability of cheap crude oil and natural gas during the past two decades, plus the criticisms of Chukhanov and others, apparently have led to a reduction in official support for UGC activity, in general, and for R&D, in particular. A conscious decision was made to confine UGC work to a limited amount of experimental production activity, and, in keeping with that decision, the Angren P.S. was ordered not to produce more than 600 million m^3 of gas per year(120)—less than half the amount produced in some previous years. (In 1965 the Angren P.S. produced 1,410 million m^3 of gas[116].)

Little of substance has been published on underground gasification of coal in the USSR in recent years. A search of the relevant abstract journal—*Referativnyy zhurnal: gornoye delo* (*Abstracts Journal:*

Mining)—from January 1977 through January 1983 yielded a large number of American, French, and German references but few from Soviet periodicals. The November 1976 issue of *Ugol* contained a brief review of activities in West Germany and Belgium(121). In May 1978 the Soviets published an author's certificate for a method of uniting, by hydraulic fracturing, separate wells drilled into coal seams; the certificate named Ye. V. Kreynin and other researchers at VNII Promgaz (discussed below)(122). Also in May 1978 an article by Ye. I. Gluzberg was published in which the process of spontaneous heating of a coal seam through which air is permeating was described by a system of differential equations(123). In an article published later in 1978, Krichko and Chernenkov of IGI made passing reference to Soviet work on UGC, noting that three *podzemgaz* stations were still in operation(177). The same year saw the publication of an article by Kreynin and Zvyaginstev of VNII Promgaz in which the authors examined UGC efforts in West Germany, Belgium, and the United States (the American program led by Lawrence Livermore Laboratories). Kreynin and Zvyagintsev were critical of the reliance of the Western projects on the "direct filtration method," arguing that Soviet experience shows that the method is not effective. They consider the direct channel methods developed by the USSR to be superior(124).

Several publications have emanated from the Institute of Geology and Geochemistry of Mineral Fuels, where three researchers—V. A. Kishniruk, Ye. S. Bartoshinskaya, and S. I. Byk—have been investigating the possibility of underground gasification of coals in the Lvov-Volynsk Basin(125). Kushniruk, the head of the Division of Coal Geology at the institute, reports that the Lvov-Volynsk Basin (in the Ukraine) has over 3 billion m.t. of underground coal reserves, only one-third of which can be mined by shaft methods. At present only six of the eighty-eight seams that have been explored are being mined(126). The three researchers suggest that UGC be applied with a number of seams to produce gas for energy purposes and as a feedstock for the production of chemicals and high-quality liquid fuel(125). In view of the worsening energy situation of the Ukraine, this proposal may receive some official consideration.

There is some very recent evidence of a revival of Soviet interest in underground gasification of coal. On June 22, 1979, a joint meeting was held with representatives from the geotechnology sections of the GKNT, the Scientific and Technical Council of Gosstroy SSSR,* the ministries of the coal, gas, and chemical industries, and various scientific research institutes and higher schools. The meeting dealt with technical problems associated with UGC, and proposals were put forward for research, development, and design work on improved stations(110).

Two years later, four papers on underground gasification of coal and shale were presented at the Second All-Union Scientific-Technical Conference on Problems of Mining Thermophysics, held in Leningrad (November 1981)(127). Soviet researchers also have published review articles in domestic and foreign journals(110, 114).

Finally, the past few years also have seen some ambitious proposals for the commercialization of UGC technology in the Soviet Union. One calls for the creation of a *podzemgaz* station near the Ryazan GRES with the capacity to produce 7 billion m^3 of gas per year (equivalent to 3 million m.t. of coal). It is estimated that such a plant would pay for itself in seven years(110).

In the longer term, it has been proposed that the USSR build fifteen to twenty stations with a total capacity of 120–150 billion m^3 of gas annually (equal to 70–75 million m.t. of coal per year)(110).

We have not seen evidence of official support for such proposals and are skeptical about their chances for implementation in the near future.

Key Organizations

Over the years numerous institutes have been involved in research and development activities relating to UGC, including the Laboratory of Hydrogeological Problems imeni F. P. Savarenskiy, the Institute of Fossil Fuels, Moscow State University, the Tatar Petroleum Scientific Research Institute, the Moscow Geological-Prospecting Institute imeni Ordzhonikidze, the Institute of Geology and Geochemistry of Mineral Fuels, and the Central Scientific Research Boiler-Turbine Institute imeni I. I. Polzunov. In 1954, for example, eighteen different institutes were involved in research on UGC (eleven affiliated

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*The USSR State Committee for Construction Affairs—the top management organ in Soviet construction.

Table 20 Organizations and Personalities Currently Engaged in Research on Underground Gasification of Coal

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All-Union Scientific Research Institute for the Utilization of Gas in the National Economy and Underground Storage of Petroleum, Petroleum Products and Liquefied Gases (VNII Promgaz), USSR Ministry of the Gas Industry, Moscow

Ye. V. Kreynin(122,124)
K. N. Zvyagintsev(114,124)
N. A. Fedorov(122)
R. I. Antonova(122)
A. F. Volk(122)
E. G. Gershevich(122)

Institute of Geology and Geochemistry of Mineral Fuels, Ukrainian Academy of Sciences, Lvov(125)

V. A. Kushniruk
Ye. S. Bartoshinskaya
S. I. Byk

State Scientific Research Institute of Mineral and Chemical Raw Materials

V. Zh. Arens(110)

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with the USSR Academy of Sciences, two affiliated with union republic academies, and five under the Ministry of the Coal Industry)(128). The activities of these eighteen organizations were coordinated by the Commission on the Problem of Underground Gasification of Coal, which was under the USSR Academy of Sciences(110).

For many years the most prominent institute in UGC research was the All-Union Scientific Research for Underground Gasification of Coal—VNII Podzemgaz. This institute was established after 1945, carried out research on UGC, and for many years published a scientific journal (*Trudy VNII podzemnoy gazifikatsii ugley*). During the mid-1950s VNII Podzemgaz was subordinate to the Ministry of the Coal Industry, but the 1958 phone directory for Moscow and a 1966 patent indicate subordination at those times to the Ministry of the Gas Industry(129). One of the last references to VNII Podzemgaz was in a USSR author's certificate published in July 1970 (No. 275,917). Some time after that date VNII Podzemgaz was reorganized, given a new mission, and renamed the All-Union Scientific Research Institute for the Utilization of Gas in the National Economy and Underground Storage of Petroleum, Petroleum Products and Liquefied Gases (VNII Promgaz).

UGC activity remains under the auspices of the Ministry of the Gas

Industry with a modest amount of R&D work being carried out by VNII Promgaz.

A list of key organizations and persons currently engaged in UGC is given in table 20.

Evaluation

The Soviets have accumulated a great deal of experience with underground gasification of shallow coal seams using normal air, but they have substantially less experience with deep deposits or with the use of steam or oxygen for combustion(113).

In spite of the modest pickup in publication activity since 1980, we see little likelihood of serious development of UGC within the Soviet Union, at least for the next several decades, because of the more favorable economics of conventional fuels such as natural gas, crude oil, and strip-mined coal. Much of the present activity (see Zvyagintsev's article in *Colliery Guardian*[114]) probably is directed at cultivating the foreign market for UGC technology in countries where the economics of underground gasification of coal are more favorable. One tangible result of such activity was the 1975 sale, to Texas Utilities Services, Inc., of exclusive U.S. rights to use and sublicense one Soviet process for UGC. The American firm, which paid $2 million for these rights, reportedly plans to adapt the process to Gulf Coast lignite(130).*

As far as domestic application is concerned, UGC technology seems likely to remain on the back burner until some time in the next century when it may be needed for the exploitation of thin, deep-lying seams of coal.

Oil Shale and Peat

Oil shale is sedimentary rock that contains organic matter. The organic matter, which is often called kerogen, is a high molecular weight mineral of variable composition. The volume of kerogen per ton of oil shale also is variable but is normally quite low; oil shale, in most parts of the world, therefore has been an uneconomical source of fuel. The designation "oil" shale, in fact, is an economic, not a geological, term since most sedimentary rock contains some amount of kerogen(132). Oil shale resources historically have been exploited only in situations in which other local fuel supplies were limited or nonexistent or in which the supply of fuel from other areas was not feasible.

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*The 1979 annual report of Texas Utilities says that a demonstration project was completed successfully in March 1979 on a thirty-acre tract near Palestine, Texas. The tests, which involved the combustion of three thousand tons of lignite at depths of up to 290 feet, indicate that the economics of the process probably are competitive with those of new gas and oil. The company is considering a pilot project that would produce low BTU gas as a supplemental fuel for an existing boiler (presumably to generate electricity)(131).

The kerogen can be utilized by direct combustion of the oil shale in boilers or by heating the oil shale to convert the kerogen to gas or liquid fuels. The heating can be accomplished *in situ* or aboveground in retorts. Direct combustion and aboveground retorting both result in environmental problems associated with the disposal of the large volumes of resulting shale ash.

Resources and Production of Oil Shale

Estimated Soviet oil shale resources are enormous, exceeding the available reserves of oil and natural gas and some of the coal reserves(133). Estimates of oil shale resources made in 1967 came to 193 billion m.t., of which 6.5 billion were suitable for extraction under current technical and economic conditions(134). The oil shale is concentrated in the Baltic area, in the middle Volga River region near Kuybyshev, and in the area near Lvov in the Ukraine. Extraction of oil shale has increased substantially since the end of the Second World War, but its share in the fuel balance peaked around 1965 at 0.8 percent and has declined since then to 0.5 percent. Production rose to 11.8 million m.t.s.f. in 1980 but then dropped to 10.5 million m.t.s.f. in 1983(34). The Baltic region currently accounts for nearly all Soviet oil shale output, but recently announced plans call for an increase in overall output, coupled with a shift of production to the Volga region(135). The share of oil shale subjected to retorting is to grow; the resulting shale oil will be used as a boiler fuel and as a chemical feedstock. The Estonians intend to devote special attention to the chemical industry uses of shale oil in accordance with an Estonian government program on comprehensive oil-shale utilization that was adopted in June 1981(136).

Direct Combustion of Oil Shale

Currently, about 73 percent of Soviet oil-shale production is burned directly in two state regional power stations (GRES's) located in the Estonian SSR—the Baltic GRES and the Estonian GRES(137). In the late 1970s the stations had a combined capacity of 3,500 MW and generated 18 billion kwh of electricity per year(138, 139). A third Estonian station (2,500 MW) is planned, but expanded nuclear capacity in the region may make this unnecessary(136).

Construction of the Baltic GRES began in 1955, and the first generating unit came on line in late 1959; construction was not completed until the end of 1965. The plant has 1,600 MW of capacity, consisting of eight 100-MW units and four 200-MW units. In the 1960s the plant dominated Estonian power generation, accounting for 84 percent of the republic's total generating capacity by 1965(140).

The Estonian GRES came on line in late 1969 and reached full capacity (1,600 MW) in 1972(104). With these two large plants in operation, the government was able to shut down a number of small power plants and still have large amounts of surplus power for export to other areas of the Soviet Union(104, 140). The boilers of the Estonian GRES at present are being converted from direct combustion of shale to combustion of shale oil (see below).

Direct combustion of shale results in the emission of heavy ash and sulfur compounds into the air and the accumulation of large volumes of spent shale. As a result of these environmental problems, direct combustion is now being limited to 200-MW units (or smaller) that are equipped with 250-m smokestacks.

*Oil-Shale Conversion**

Introduction. Commercial aboveground conversion of oil shale into liquid or gaseous fuels has been practiced at one time or another in many countries besides the Soviet Union, including the United Kingdom (Scotland), Germany, China, and the United States(143). Currently, however, commercial oil-shale conversion activities are limited to the USSR and, to a much more limited extent, to China(132).

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*This section evolved from research originally performed by Timothy P. Spengler. See reference(142).

Numerous types of retorts have been developed that differ widely with respect to their technical features and to the specific products that they yield. In all retorts, however, pyrolysis* converts the kerogen into three principal products: (1) crude shale oil, which is condensed from vapors; (2) a mixture of gases including hydrogen, oxides of carbon, hydrogen sulfide, and hydrocarbons such as methane; and (3) a solid residue, resembling coke, that is mixed with the noncombustible spent shale (ash)(143). The mix of these products depends upon the temperature, pressure, and speed of the pyrolysis process.

At present there are three major oil-shale processing plants in the USSR, two of which are located in Estonia, at Kohtla-Jarve and Kivioli. The third is located at Slantsy in nearby Leningrad Oblast. A fourth, but small, plant is located at Syzran in the Volga shale region, while a new pilot oil-shale processing plant at Skole, near Lvov, began operating in 1981(99). As of 1977, the three major plants were producing a total of 750,000 m.t. of shale oil per year; of this amount, 350,000 m.t. were being refined into fuel oil and the remainder into chemical feedstock(144). The Kivioli plant was producing 500,000 m.t. of shale oil in 1982, and output was to rise to 700,000 m.t. by 1985(145).

Gasification Processes. Soviet oil-shale processing has been based mainly on aboveground retorting processes that yield large amounts of gas.** Thus, in Soviet parlance, the purpose of this technology often is termed "gasification," although liquid and solid substances also are produced, and the retorts used for this purpose are called "gas generators." As of 1974, gasification of oil shale accounted for more than half of all oil-shale conversion(146).

Over the years the USSR has made significant progress in increasing the size and efficiency of its retorts. The earliest gas generators were patterned after foreign retorts, such as those used in Scotland. These designs proved to be ill-suited for the high-grade, kukersite oil shale of Estonia. Despite attempts to compensate for this, the early retorts performed inefficiently and could process only tens of metric tons of raw materials per day. Therefore, domestic R&D focused on the design of gas generators to handle Estonian oil shale. By the early 1950s the Soviet oil-shale processing industry had gas generators capable of processing 100 m.t. of oil shale per day; three such generators were developed by the Leningrad Branch of the State Institute for the Design of Synthetic Liquid Fuel and Gas Enterprises (Lengiprogaz)(146).*

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*Pyrolysis refers to the breaking down of complex materials into simpler materials by means of heat(143).

**Methods for the underground gasification of shale were developed during the 1950s by ENIN, VNIINP, and the Institute of Chemistry of the Estonian Academy. The ENIN method, which processed two hundred tons of oil shale per day, was used more than the others. Although the VNIINP method tested well, it was not adopted(147).

Another advance came in the late 1950s and early 1960s with the development of a new Soviet gas generator designed to process up to 150 m.t. of shale per day(146). In this generator the raw oil shale was pyrolyzed using a combined steam-air heat transfer agent, producing shale oil, gas, and a coke residue. Following the initial pyrolysis, some of the gas was recycled to gasify the coke. The end product was a gas with a caloric value of about 900 kcal/m^3(148).

Two versions of this gas generator were designed. In the version that was developed jointly by Lengiprogaz and the All-Union Scientific Research Institute for the Processing of Oil Shale (VNIIPS),** the heat-transfer agent was fed into the center of the pyrolysis chamber and spread outward to its periphery(148). The second version was designed so that the heat-transfer agent flowed in the opposite direction—from the periphery to the center. Extensive experimentation by the Scientific Research Institute of Shales (NII Slantsev) and the Kohtla-Jarve Oil-Shale Processing Combine showed the latter design to be more efficient, and it became the standard unit for oil-shale conversion in the Soviet Union.

The largest gas generator developed to date has a rated capacity of 1,000 m.t./day. The development of this unit was begun in 1970 by NII Slantsev, together with Lengiproneftekhim and the Kohtla-Jarve Shale Processing Combine(149); a draft design was completed in 1973(146). The first generator was built in 1981 at the Kohtla-Jarve combine, but it did not reach its rated output until July 1982(150,

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*The name of this facility may have been changed later to the Leningrad Branch of the State Scientific Research and Design Institute for the Petrochemical Industry (Lengiproneftekhim).

**In 1959 or 1960 this institute was renamed the All-Union Scientific Research Institute for the Processing and Use of Fuel (VNIIT). It is not known if this institute exists today.

151). The design involves a "revolving reactor"; the reactions take place in a mixture of hot ash and dry, crushed oil shale(151). Although this unit represents the state of the art in Soviet gas generators, and a significant increase in size over the previous units, it has only about one-tenth of the capacity of retorts being planned for commercial processing in the United States(143). A 3,000 m.t./year Soviet generator, however, is in the demonstration stage(152).

The ENIN Process. Gasification processes account for most, but not all, of the oil shale converted in the USSR. Alternative conversion methods with a greater share of liquid products have been under development, although only one method—the solid heat-transfer agent pyrolysis process developed by ENIN—has been commercialized. ENIN began working on oil-shale conversion more than forty years ago. In 1945 I. S. Galynker of ENIN invented a method for thermal processing of fine-grain solid fuel using a solid heat-transfer agent; five years later, ENIN proposed using this method to process oil-shale fines that had traditionally been burned directly as fuel for energy production(153, 154).* The ENIN process, if successful on an industrial scale, will permit more oil shale to be channeled into conversion and, hence, out of direct combustion.

The solid heat-transfer agent oil-shale process appears to be an adaptation of a basic technology that ENIN has been developing for high-speed pyrolysis of low-grade solid fuels, especially brown coal(139). (See chapter 5.) The ENIN oil-shale process works as follows: after being dried in a draft of hot combustion gases, the shale fines pass into a separator, where the gases are removed; the dry shale is then fed into a reactor, where it is mixed with the solid heat-transfer agent (shale ash generated during the process) and is pyrolyzed, yielding a mixture of gas plus oil and water vapors; after the dust is removed from this mixture, the gas, oil, and water are separated in a condenser(139).

The characteristic feature of the ENIN method is that the spent shale that is generated during the pyrolysis phase is recycled to generate and transfer heat.* The coke-like portion is burned in a combustor, thereby heating the ash residue and the stream of air blown into the combustor. The hot ash circulates back through the system to dry and pyrolyze the raw shale(139). Eventually, the ash is cycled out of the system and can be used in building materials (e.g., cement), road construction, fertilizer production, and as a raw material for making alumina.

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*As of 1978, fine and pulverized shale accounted for more than 60 percent of total shale mined in the USSR, and this share was expected to increase to 80–85 percent in the following ten to fifteen years(155). The growing proportion of fine-grain shale is the result of increasing mechanization of mining operations.

The principal products of the ENIN process are shale oil and gas, the latter having a high caloric content (10,000–12,000 kcal/m^3 for Baltic shale) due to the high concentration of olefins (as much as 36 percent by volume)(139). These olefins, which are valuable to the chemical industry, may be recovered, but doing so lowers the heat value of the gas(141).

ENIN—assisted by the Institute of Chemistry of the Estonian Academy of Sciences, NII Slantsev, and a number of industrial enterprises—has now commercialized its process. After initial tests of the process on a small experimental unit (2.5 m.t. of shale/day) at the "Ilmarine" Plant in Tallinn, successful trials were conducted on an industrial prototype UTT (solid heat-transfer agent) unit built at the Kivioli Shale-Chemical Plant in 1953. The UTT unit was designed to process 200 m.t. of shale/day, but stable operation was achieved at a rate of only 180 m.t./day(153). In the late 1960s a larger pilot unit—the UTT-500 (500 m.t./day)—was built at the Kivioli plant(149). Successful operation of the UTT-500 led to the design of the largest unit to date, the UTT-3000, which will process shale at the rate of about 1.2–1.9 million m.t./year(135). The UTT-3000 is expected to produce 130,000 m.t. of shale oil and 42 million m^3 of gas annually(139).

A major application of the solid heat-transfer agent method will be in the production of boiler fuel for electric power plants. To this end, work is in progress on converting the boilers of the Estonian GRES to burn shale oil instead of raw shale. The oil will be supplied by two UTT-3000 units. Construction of the first UTT-3000 was under way in 1977, and it was hoped then to put this unit into practice as early as the following year(156). The UTT-3000 units are now said to be in operation at the GRES, but defects continue to limit output(135). Technical data on the UTT-3000 are almost entirely lacking. According to a 1980 report, however, the oil shale at the Estonian GRES is heated to 800°C and enters a distillation reactor at 350°C(157).

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*The ENIN method appears to be the one embodied in a processing unit known by the West as the Soviet "Galoter" retort, which uses the spent shale as a heat-transfer agent and which is said to bear a striking resemblance to the TOSCO II indirectly heated retort designed in the United States(143).

The IGI Process. In the 1950s the Institute of Fossil Fuels (IGI) developed a method for converting solid fuel into liquid fuel and chemicals. The method involved dissolving the solid material in an organic solvent at relatively low temperatures (380–440°C) and pressures (20–30 atm). The first liquefaction phase lasted from ten to thirty minutes and used material ground into fine particles (0.2–0.3 mm). The resulting solution was then distilled at a temperature of 300–320°C. The lighter distillates (gases and vapors) were condensed, while the heavy residue or sludge was subjected to further processing, either by filtration or by distillation to coke. The method was designed to use solvents generated during the process itself(158).

As far as we know, the IGI process has never been commercialized, and R&D work on the process may even have been suspended until recently when, in 1980, three scientists at IGI published an article apparently aimed at generating renewed interest in this process as a promising technique for processing oil shale on an industrial scale(159). This article reports results of laboratory experiments on a continuous-action unit for Baltic shale.

Although based on the work done at IGI in the 1950s, the new experiments incorporated some changes, primarily with regard to parameters of the process. In the thermal distillation phase, the temperature range (400–430°C) was within the range of that in the earlier experiments, but the pressure was raised to 30–50 atm, and the maximum duration of this phase was cut in half (10–15 minutes). Subsequent processing of the dissolved shale was accomplished by simple distillation at a pressure of 50 atm(159).

The continuous-action process was tested using both run-of-mine and enriched Baltic oil shale (70 percent kerogen). In both cases an average of 90 percent of the kerogen was dissolved. The main end product of the process was a heavy "extract" containing undissolved organic substances and ash. This product was found to be potentially useful for various purposes, such as the manufacture of certain plastics and as a bituminous road surfacing material. The other products were gas, liquid fuel, and water. The distillation phase generated a solvent, which was used and redistilled repeatedly(159).

Based on the successful results of these recent experiments, IGI recommended further development of its process on an industrial scale. Plans were developed to build a pilot unit at the Slantsy Shale Processing Plant, with assistance from the NII Slantsev and Lengiproneftekhim. The planned unit has a capacity of 5 m.t. of enriched shale per day(159).

NII Slantsev. The Scientific Research Institute of Shales also has been investigating the pyrolysis of oil shale in a fluidized bed; as of 1978, the institute was reported to have begun experiments with this method(147). Details of this research are not known to us.

Peat

The USSR is said to possess over 160 billion metric tons of peat (*torf*), or over 60 percent of the world's peat resources(160). The European USSR, excluding the Soviet Northwest, contains 12 percent of the peat in the USSR, while production in this area accounts for more than 80 percent of overall extraction. At present rates of extraction, these areas have reserves sufficient for only several additional decades.

Peat, an early stage of coal formation, is a very low-grade fuel with low mechanical strength. As a result, long-distance transport is not economically rational, and peat must be used locally. Peat also varies considerably in moisture and mineral content and has a fibrous structure that is hard to break down(161). Such considerations mediate against significant reliance on peat as an energy source.

Peat accounted for 5.7 percent of the Soviet fuel balance in 1940 and had fallen sharply to only 0.4 percent by 1983. During this period it appears that the average caloric content of the peat extracted also has fallen. Output in 1981 amounted to 37.2 million m.t.—up from the low level of 1980 (21.6 million m.t.) but substantially less than the 57.4 million m.t. produced in 1970(34). Over two-thirds of it has been going for the production of electricity; an additional five million m.t. of peat briquettes are consumed for household heating annually(162). The briquettes are produced by drying and then pressing the cut peat(163). Peat briquettes are the primary fuel in

Belorussia's 2 million furnaces and boilers and are described by one source as being convenient to use, having a relatively high heat of combustion and a low ash content(163).

The use of peat in electric power plants in the Soviet Union dates back to 1914 when a 15-MW station was commissioned fifty miles east of Moscow. By the middle 1960s the USSR had seventy-seven peat-fueled electrical power stations, most of which were quite small (50 MW or less)(104). Many of the currently existing peat-fueled stations, which have a capacity exceeding 5,000 MW, are to be switched to natural gas as supplies of the latter become available(162).

The Soviets indicate that peat will be used less as a fuel in the future and more as fertilizer in support of the National Food Program and as a source of other chemicals. However, the production of peat briquettes for consumers is likely to increase to 8–9 million tons per year, and certain regions will continue to rely heavily on peat as an industrial fuel(160).

The only peat-related R&D we have identified is the work on peat briquetting being conducted at the "BelNIITopproyekt" Institute (the Belorussian Comprehensive Project-Survey and Scientific Research Institute of the Fuel Industry) in Minsk, Belorussia. One project involved the development of a high-productivity device for drying the cut peat (the most expensive step in preparing briquettes). The new dryers are said to be in the use in four of Belorussia's peat briquetting plants. A second project involved salvaging coal fines and making productive use of them by pressing the fines into composite peat-coal briquettes. In the fall of 1982 it was reported that this process was being introduced at the "Berezinskiy" plant near Minsk. Finally, BelNIITopproyekt has worked on ways to reduce emissions of peat particles into the atmosphere during briquetting by recycling them into the drying furnaces(163).

Hydrogen

Soviet interest in hydrogen as a fuel can be traced back at least as far as World War II. During the siege of Leningrad when gasoline became scarce, spent hydrogen from barrage balloons was used in the engines turning winches holding the balloon cables. Approximately fifty gasoline-powered engines were successfully adapted to burn hydrogen during the crisis(164).

In recent years the growing concerns about supplies of fossil fuels, together with concern about the environmental consequences of burning these fuels, have led to worldwide interest in hydrogen, an energy source that could offer the convenience of crude oil and natural gas, yet burn with practically no harmful by-products. Soviet scientists have followed world developments in hydrogen technology and a great interest has developed in the USSR Academy of Sciences in the possibility of someday converting the Soviet Union into a "hydrogen economy" in which hydrogen would be the most common fuel,* displacing crude oil, natural gas, and coal.

Programs, Organizations, and Personalities

Hydrogen Production Programs. Hydrogen can be produced in a number of ways, but some approaches are inconsistent with the idea of a "hydrogen economy." Steam reformation of natural gas and gasification of coal are well-established processes for producing hydrogen for present industrial uses, but it makes very little sense to base a new era of "unlimited" and "environmentally safe" energy on fossil fuels that are available in limited quantities or that pollute the atmosphere.

Much of the discussion has assumed that hydrogen would be produced from water. Electrolysis has received considerable attention since it is a well-tested method. Assuming that electricity for this purpose should not come from power plants based on fossil fuels, most advocates have focused on nuclear power. Valeriy Legasov, a deputy director of the Institute of Atomic Energy imeni Kurchatov, suggested in 1977 that hydrogen might be produced by electrolysis during off-peak periods(165). (Presumably the hydrogen could be consumed to produce supplemental electricity during periods of peak electricity demand or could be used for entirely different purposes.) An analogous proposal has been offered by V. I. Sidorov of NPO "Tsiklon" who suggests that excess electricity from wind installations be used to produce hydrogen by electrolysis and that the hydrogen be burned to generate electricity from steam-gas turbines when the wind dies(28). Babintsev (also of Tsiklon) has gone further, visualizing wind power as a source for cheap electrolytic production of hydrogen(23).

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*Some writers prefer to speak of hydrogen as an "energy carrier" rather than as a primary fuel, since it does not occur naturally in readily usable form and would require large amounts of energy from other sources (e.g., nuclear energy) to produce.

In addition to nuclear and wind energy sources, the use of solar energy also has been studied by the Soviets for the production of hydrogen. Both solar electrolytic and solar thermochemical techniques have been developed by the Azerbaydzhan Academy of Sciences. A wind-energy electrolytic method also has been developed there. Jointly with the Institute of Chemical Physics of the USSR Academy of Sciences, the Azerbaydzhan Academy of Sciences has been doing research on the radiation decomposition of water as another means of producing hydrogen(166). The use of semiconductor catalyst electrodes in decomposing water by the effect of solar energy is also being investigated at Soviet institutions(167, 168).

The economics of solar- and wind-based electrolysis apparently have not yet been worked out, but general enthusiasm for electrolytic approaches to the production of hydrogen seems to have waned. Legasov, one of the strongest Soviet advocates of a hydrogen economy, still favors the use of nuclear reactors, but he now thinks it would be more logical to make direct use of the *heat* from nuclear reactors to break water into hydrogen and oxygen rather than using the reactors to produce electricity first(169).

Other than electrolysis, there are two principal methods of separating hydrogen through the use of nuclear energy. The first is thermal separation in a high-temperature reactor, and the second is separation through reactions in a "low-temperature" plasma (ionized gas).

Thermal separation involves the reaction:

$$4H_2O \rightarrow 4H + 4OH \rightarrow 3H_2 + O_2 + 2OH$$

which takes place at a temperature of about 2,500°C, obtainable in a high-temperature reactor. There also are several thermochemical processes, each of which involves a series of chemical reduction reactions that are caused to take place at selected temperatures. These techniques of utilizing the heat of a nuclear reactor to separate hydrogen from water have been discussed in a 1978 book of which Legasov is the chief editor(170).

Certain processes of water decomposition and hydrogen production in a nonequilibrium plasma have an energy efficiency close to that of the electrolytic and thermochemical methods and also are characterized by high productivity and simplicity of technological achievement, according to a 1978 paper by Legasov et al.(171). Two principal types of processes were described:

(1) Water-vapor decomposition in a nonequilibrium plasma, and
(2) Hydrogen production in nonequilibrium plasma-chemical systems $H_2O - CO_2$.

The chemical reactions in the first type of process are complex; however, the second type of process may be described as follows (172):

$$CO_2 \rightarrow CO_2^* \rightarrow CO + \tfrac{1}{2} O_2$$
$$CO + H_2O \rightarrow CO_2 + H_2.$$

Thus, the plasma-activated CO_2 acts as a catalyst and may be recovered. The second reaction, called the "shift" reaction, proceeds intensively in the temperature range 250–400°C.

In connection with production of hydrogen in a nonequilibrium plasma, it has been noted that Legasov and M. F. Zhukov, a deputy director of the Institute of Thermophysics of the Siberian Division of the USSR Academy of Sciences, share a common interest in plasma chemical reactors. Further development of such hydrogen production processes can be expected through programs directed by them in their respective institutes.

Economical production of hydrogen from water could significantly extend the use of nuclear energy in the Soviet Union and could provide a solution to the load management problem of nuclear reactors.

The Soviets also are investigating biochemical approaches to producing hydrogen. Scientists at Moscow State University, the Institute of Photosynthesis (USSR Academy of Sciences), and the Institute of Physiology of Plants of the Ukrainian Academy are developing biological photosynthesis methods in which masses of chlorella algae held in glass tanks are exposed to sunlight, grow, and generate hydrogen. At the present time laboratory tests are under way and researchers are investigating the influence of temperature, light intensity, color, and biocatalysts on the processes(173, 174). Scientists at the Institute of Photosynthesis in Pushchino reportedly have achieved a hydrogen production rate of twenty-five liters per hour from fifty grams of biomass (a mixture of chlorella and certain bacteria)(175).

Research on biochemical methods of producing hydrogen enjoys the blessings of the Presidium of the USSR Academy of Sciences, which instituted a special program, "Project Photohydrogen" (*fotovodorod*), in 1978(174). Important personalities in these efforts include I. Berezin, a corresponding member of the USSR Academy and dean of the *fakultet* of chemistry at Moscow State University (173), and N. I. Bidzilya, candidate of biological sciences and head of the Laboratory of Photobiology of the Ukrainian Academy's Institute of Physiology of Plants(174).

Finally, several unusual approaches to producing hydrogen are being investigated. One involves the recovery of hydrogen from by-products of the oil-refining and petrochemical industries. Specifically, the All-Union Olefin Scientific Research Institute is studying a cryogenic absorption process for obtaining hydrogen with a concentration as high as 98–99 percent from industrial gases containing hydrogen (168). A second unusual production method, which is economically advantageous in some industries, is the use of the heat of industrial exhaust gases and special thermoelectric reaction cycles to produce hydrogen. The first Soviet prototype installation using the latter method has been designed by the Belorussian State Institute for the Design of Enterprises for the Hydrolysis Industry and Microbiological Synthesis(176).

Hydrogen Storage and Transmission Programs. Because of the flammability of hydrogen, there is a concern about how best to store it, particularly in motor vehicles or aircraft. Hydrogen can be stored as a compressed gas or, if cooled to cryogenic temperatures, as a liquid. But both methods present technical problems.

Another approach, which is being investigated by the Ukrainian Academy's Institute of Inorganic Chemistry, is to bond hydrogen to metal filings to form hydrides. Such filings would be carried in a special cylinder and would release the hydrogen when heated. Soviet researchers estimate that one cubic decimeter of a suitable metal could hold enough hydrogen to power an automobile for 400 to 500 kilometers(174). One metal that the Soviets are evaluating as a hydrogen storage medium is pulverized lactan nickel, one kilogram of which is able to absorb about fourteen grams of hydrogen(177). Later reports indicate that 150 grams of lanthanum-nickel hydride can store up to two kilograms of hydrogen—enough to power a microbus for 250 kilometers. A unit volume of this hydride reportedly will hold as much hydrogen as an equal volume after compression to 1,000 atmospheres of pressure(178). In the United States lanthanum is relatively expensive, selling for about $69 per 50 g (179). Institutions of the Azerbaydzhan Academy of Sciences have been studying hydrogen absorption in intermetallic hydrides and zeolites(168).

Although experience with pipeline transport of hydrogen is limited, with lines ranging from only 10 to 100 km, there do not seem to be any serious barriers to such transport. During the late 1960s and early 1970s the feasibility of moving hydrogen in underground lines was demonstrated in the USSR and elsewhere without any serious problems or accidents. Hydrogen embrittlement of pipelines and other metal components has been considered a problem, but it is claimed that this problem can be solved by adding small amounts of oxygen to the hydrogen(180).

Hydrogen Application Programs. Soviet advocates of a hydrogen economy have discussed a variety of uses of hydrogen as an energy carrier, but most of the applications research has been directed toward motor vehicles.

In 1968 tests were carried out in Novosibirsk on the GAZ-652 truck engine, comparing hydrogen and gasoline as fuels. The tests, which were conducted at the Institute of Theoretical and Applied Mechanics of the Siberian Division of the USSR Academy of Sciences and supervised by Academician V. V. Struminskiy, required few modifications of the engine but did require some work on the development of a thermally insulated cryogenic tank for the hydrogen(181, 182). This work led to the development of a highly effective vacuum-shielded insulation that is now being used in cryogenic protection of railroad tanks and also to the development of a hydrogen tank for the Volga GAZ-24 automobile(182).

In more recent work under the direction of Academician Struminskiy, it was found that if 5 to 10 percent hydrogen is added to gasoline, the completeness of fuel combustion can be increased significantly. As a result, the engine's efficiency is improved by 40 to 45 percent. Perhaps most important, it was found that the content of carbon monoxide in the exhaust gases is reduced to less than 1 percent of that of conventional exhaust gases(183, 184).

Work on the development of hydrogen-powered automobiles has continued and has included efforts by the Institute of Physical Chemistry of the USSR Academy; the Central Scientific Research and Design Institute of Fuel Equipment for Automobile, Tractor, and Stationary Engines, headed by Yu. Sviridov(164); the Ukrainian Academy's Institute for Problems of Machine Building under A. N. Podgornyy(164, 178, 185); and the Kharkov Highway Institute(185). Researchers at the last two institutes have developed equipment and procedures for running automobiles on pure hydrogen and have tested these in "Zaporozhets," "Zhiguli," "Moskvich," "Volga," and other makes of Soviet automobiles, as well as LIAZ motor buses(185). A series-produced RAF-2203 microbus has been used in experiments by specialists of the USSR Academy of Sciences' sector for nonhomogeneous media mechanics. Two cryogenic vessels containing 5.6 kilograms of liquid hydrogen were installed in the luggage compartment (183). Soviet researchers also are investigating electric motor vehicles based on hydrogen(185).

Although these efforts continue to be experimental for the most part, plans already have been announced for one of the first operational uses of hydrogen in motor vehicles. This was to involve the conversion, before 1980, of trucks used in the strip mines of Kursk to operate on a mixture of hydrogen and gasoline to reduce the accumulation of exhaust fumes at the bottom of the mines(185). We have not heard the outcome of this effort.

The Soviets also project the economical use of hydrogen in industrial welding, production of protein biomass, drying grass meal, and purifying artesian wells (by explosion). These examples of the use of hydrogen have been shown to be economical even if the hydrogen is obtained by electrolysis of water—particularly with the creation of integrated production(176).

Finally, the Soviets are considering the employment of hydrogen in metallurgy as a substitute for coke in iron production and as a low pollution heat source(183).

Evaluation

Advantages and Disadvantages of Hydrogen as a Fuel. Soviet scientists see a number of advantages to be gained from using hydrogen as a fuel. Legasov notes that "in 1970 alone, thermal electric power plants discharged up to 80 million tons of sulfur dioxide, millions of tons of ashes, carbon dioxide, and mercury vapors into the planet's atmosphere"(169). Pure hydrogen, of course, burns to yield harmless water vapor. However, it is not necessary to burn pure hydrogen to realize environmental advantages: the dilution of ordinary gasoline with as little as 3 to 5 percent hydrogen reportedly reduces automobile pollution sharply and results in 20 to 30 percent savings of fuel (187).

Unlike fossil fuels, hydrogen is seen as available in practically unlimited quantities because it can be produced from water. In addition, it has potential advantages over other energy sources in terms of ease of storage and transportation. Babintsev of NPO Tsiklon argues that the cost of transporting hydrogen by pipeline over a distance of approximately 500 km is only one-eighth the cost of transporting an energy-equivalent amount of electricity via overhead high-voltage power lines(23). Since hydrogen contains a high energy potential per unit of weight, it would reduce the takeoff weight of airplanes fueled with it(186). Legasov, who sees hydrogen ultimately displacing even electricity in many uses, has noted that hydrogen is much easier to store than is electricity(187).

Soviet advocates of a hydrogen economy argue that it is relatively easy to adapt many existing pieces of equipment to the use of hydrogen—e.g., automobiles require only minor carburetor adjustments(186). (The ease of burning hydrogen in vehicles must, of course, be balanced against added difficulties of carrying hydrogen in such vehicles.)

The big disadvantage of hydrogen at the moment is its cost. In the United States hydrogen is produced by the steam reformation of natural gas at a cost of about $3 per million BTU (1978 estimate). Hydrogen produced through the gasification of another "scarce" fossil fuel —coal—costs about $5 per million BTU. But if "abundant" water is used—for example, in electrolysis—the cost is in excess of $6 per million BTU(180).

In the Soviet Union the cost of hydrogen produced by electrolysis is two and a half to three times higher than if it is produced from natural gas (1977 estimate)(165). Specific estimates of the cost per metric ton of standard fuel (m.t.s.f.) from natural gas and various sources of hydrogen were published in 1980:

Natural gas	40 rubles/m.t.s.f.
Hydrogen (steam reformation of natural gas)	60–72 rubles
Hydrogen (electrolysis at 350–450°K with nuclear electricity)	110–200 rubles
Hydrogen (electrolysis at 1,000–1,300°K)	90–120 rubles(188).

By the fall of 1984 hopes were being voiced that new thermochemical installations and electrolysis units under construction would make it possible to reduce the power consumed in the production of hydrogen to half the amount required when hydrogen is obtained from natural gas(178).

Time Frame for Development. Since the successful tests of the GAZ-652 engine in 1968, there have been flurries of activity and attempts by many R&D organizations to jump on the hydrogen bandwagon. The USSR Academy of Sciences funded "Project Photohydrogen," which called for intensive theoretical and applied research over the period from 1975 to 1979 on methods of producing hydrogen by photosynthesis processes(174). In 1976 experiments began in Kharkov in which automobiles were converted to hydrogen operations(186, 189). By 1980 trucks in Kursk strip mines were to be converted to hydrogen(186). In mid-1980 it was reported that several taxis in Kharkov were using a mixture of hydrogen and gasoline on a trial basis(190). By late 1984 these Kharkov taxis had accumulated more than three years of operating experience, and "Rafik" passenger cars from the Riga Experimental Bus Plant were to go into taxi service in Moscow(178).

In spite of the number of R&D projects under way, hydrogen utilization is clearly in an experimental stage. By the year 2000 hydrogen might be an important fuel in the Soviet Union. But in the meantime, given the abundance of comparatively inexpensive fossil fuels in the Soviet Union, it seems unlikely to have a major impact on the Soviet energy picture.

Chapter 8 Energy Modeling: Achieving an Optimum Mix of Energy Technologies

As indicated in chapter 2, the S&T forecast holds a preeminent position in Soviet energy R&D planning. Forecasting is central to the formulation of long-range strategies for the rational planning of R&D programs that will ensure the availability of the required technologies when the need arises. Planning begins with the selection of a forecast variant to serve as a "main direction" of S&T development. (Energy-related main directions are listed in appendixes A, B, and C.) The ultimate utility of R&D programs therefore depends greatly on the reliability of the forecasting methodologies and the manner in which variants are chosen. Considerable attention is now being given in the USSR to developing (1) computerized planning systems for the energy sector and (2) recommendations for the development and exploitation of the fuel and energy complex. This chapter, however, will deal with the second of these major objectives–optimizing the production structure of the fuel and energy complex. An examination of the energy modeling literature should provide us with valuable insights into Soviet perceptions of their future energy situation and their plans to develop technologies to enable them to cope with the growing shortages of traditional fuels in the European part of the USSR.

Development of Soviet Energy Modeling (1920–70)

Soviet attitudes toward systematic, quantitative approaches to economic problems have developed in an intellectual environment that is at root, if not always in practice, congenial to such approaches. The Marxist-Leninist worldview is conditioned largely by the tenets of dialectical materialism in which the world is held to consist of matter-energy alone and is held to develop in a manner describable by means of dialectical logic (the successive resolution of contradictions)(1). Dialectical materialism is considered to be a valid framework for understanding not only the physical world, but also for understanding the nature and development of human society. The task of the economist, for example, is to discover the "laws" underlying the development of the economy through examination of current and historical conditions and to use these laws to plan economic development. Faith in this approach is not dimmed by any current inability to do so.

As a consequence of this rational, materialistic worldview, the Soviets became early adherents of cybernetics, since cybernetics appeared to be based on the same reductionist principles as dialectical materialism(2). Academician L. A. Melentyev, the leading Soviet energy modeler, has even stated that the early Western cyberneticists such as Wiener, Ashby, von Neumann, and others had actually begun to adopt dialectical thinking, although not consistently(3).

One of the most important cybernetic methods (as perceived by the Soviets) is mathematical modeling, in which a system of interrelated equations provides a description of some aspect of the physical or social world. The division of a real-world system into its apparent elements or components and the definition of the interactions between them is known as systems analysis, another science of growing importance in the USSR. The detail of the model is then filled in by specialists working in the area under investigation.

The Soviets claim that the first real use of the systems approach was their study of the large-scale power engineering problems connected with their fifteen-year State Plan for the Electrification of Russia (GOELRO), developed in 1920(4). The methodology behind this approach received further development in the 1930s by G. M. Krzhizhanovskiy, for whom the State Power Engineering Institute (ENIN) in Moscow is named. The fuel and energy "system" was treated by Krzhizhanovskiy as a unified whole from extraction through consumption; the system was balanced using a series of tables for the major factors and levels of hierarchy of the system. The advent of computer technology, however, has led to the abandonment of this approach since the computer has made it possible to use mathematical modeling and to make further developments in systems analysis techniques.

The contemporary stage of Soviet energy modeling began around the early 1960s. The first computerized energy model was created at the Institute of Electronic Control Machines, then under the AN SSSR, in 1959–60(5). This model was developed further by the Laboratory of Power Engineering Systems of the Siberian Power Engineering Institute (SEI), SO AN SSSR, in Irkutsk in 1962(5, 6). A report on SEI's effort is contained in an article published in the journal *Teploenergetika* in 1962(7). The discussion and conclusions were methodological; no energy projections were presented.

In 1964 a pair of articles was published by L. A. Melentyev and A. A. Makarov in the third issue of the journal *Izvestiya Akademii nauk SSSR, seriya energetika i transport.** Makarov's article dealt with improvements in the methodology used in the 1962 effort cited above(10). Melentyev reported on the results of a modeling effort that appears to be the same as that described by Makarov(11). (This represents the first publication of modeling results of which we are aware.) The projection called for a substantial growth in nuclear electrification beginning in the 1970s and a growth in the share of coal in total energy production through the remainder of the century. The projection also called for construction of large-diameter oil and gas pipelines extending from north Tyumen (Western Siberia) and Central Asia to the European USSR. (Subsequent events have proven his nuclear and coal projections to be overly optimistic.) Gosplan and computer center had accepted the model for use in planning even though Melentyev was of the opinion that available data were insufficient to make more than limited, though still valuable, use of the model.

In 1967 Melentyev and Makarov published a pair of articles in *Ekonomika i matematicheskiye modeli,* the prestigious journal of the Central Economic Mathematics Institute (TsEMI), Moscow, of the AN SSSR(12, 13). Both articles dealt entirely with methodological problems. Makarov indicated that SEI had developed at least three distinct models. One of these models was being used to make fifteen- to twenty-year energy projections (the so-called abbreviated model); while another was being used to make five- to ten-year projections (the so-called expanded model). The development of long-range energy forecasts supported Gosplan efforts to generate long-range economic plans, a requirement then being levied on them by the Brezhnev-Kosygin regime, which had assumed power in 1964. The importance of the long-range plans would continue to grow throughout the 1970s.

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*L. A. Melentyev and A. A. Makarov are the leading energy modelers in the USSR and were involved in much of the work reported on in this chapter. Melentyev was the director of SEI between 1963 and 1970. He later became a department head at the Institute of High Temperatures (IVT), AN SSSR, in Moscow(8). Makarov was affiliated with SEI until the end of the 1970s but recently has been identified as a sector head at IVT(9). There is some evidence, however, that Makarov has maintained some level of affiliation with SEI. Recent publications alternately list his organization as IVT and SEI.

Descriptions of Selected Energy Models (1970–80)

Four general types of mathematical models have been developed. These include (1) models of the general energy economy; (2) models of specific energy sources, such as nuclear electrification; (3) regional energy models; and (4) models to support the design of particular pieces of hardware used in the energy sector. Models of the general energy economy generate scenarios for medium time periods (ten to fifteen years), but also for long-range periods (thirty to forty years). The long-range forecasts are generated in combination with inputs from models of the development of the economy as a whole(14). Branch and regional models generate *zamykayushchiye zatraty*, something akin to shadow prices, which are differentiated by energy source, region, time, and final demand. These prices operate like long-run marginal costs and can be use to evaluate the economic efficiency of various scenarios of fuel and energy use(15).

Models of the general energy economy

Vigdorchik, Makarov, et al. (1972). A description of an energy model, developed in 1972 by the Siberian Power Engineering Institute, the "Elektrosetproyekt" Institute, VGPI (expansion unknown), the All-Union Scientific Research Institute of the Petroleum Industry, and the Main Computer Center of Gosplan USSR, was published in the journal *Planovoye khozyaystvo* in February 1975(16). The time frame of the effort was not specified, but it is most likely that the period from 1975 to 1990 was considered because the effort then could support development of the long-range, comprehensive S&T program being implemented for that period (see chapter 2).

The model contained the following concepts: (1) energy demand, varying by 10 to 15 percent; (2) extraction of high-quality fuel (oil and gas), chiefly from Western Siberia; (3) extraction of Kansk-Achinsk, Kuznetsk, and Donets coal; and (4) capacity of nuclear power plants. The authors developed eighty scenarios of possible combinations of the variables, based upon various assumptions of probable levels of output. Next, an unidentified but presumably linear modeling technique was used to find the optimal solution for each combination. In a first iteration the objective was to minimize total cost. The resulting variant was designated the "optimal" variant.

In a second iteration the authors calculated an "effective" variant that took into account the risks involved with the production of certain fuels (e.g., the location of new reserves of oil or the application of novel technologies for power transmission). The goal here was to increase the "reliability" of a given fuel and energy balance.

Finally, a "rational" variant was calculated that took into account the volume of capital investment in, and increases in output from, the nonenergy branches of the economy that would be needed to implement the variant.

The results of this modeling effort suggested that the Soviets should implement the following programs:

(1)Assimilate the oil and gas resources from Western Siberia and build the necessary pipelines;
(2)Introduce nuclear power station capacity sufficient to satisfy the growth in demand for electrical power in the western and central regions up to and including the Volga region;
(3)Create a Kansk-Achinsk Fuel and Energy Complex with levels of coal extraction exceeding the Donbass and with coal conversion and treatment plants.

These goals effectively describe the broad goals of Soviet energy policy in the Tenth and Eleventh Five-Year Plan periods.

Melentyev and Makarov (1974). This model was described in a 1974 article published in the journal *Izvestiya Akademii nauk, seriya energetika i transport*(17). The model, tested by the Siberian Power Engineering Institute and the Institute of High Temperatures, also covers a period of ten to fifteen years.

Three variants of fuel and energy development were estimated. These included: (1) an "optimal" variant, the variant for which the total cost is minimized; (2) a "cautious" variant that assumes significant constraints on the production of oil, nuclear fuel, and, to a lesser extent, natural gas; and (3) an "intermediary" variant, representing a compromise between the first two that is more reliable and adaptable. About one hundred scenarios were calculated.

The authors provided data on one illustrative scenario. The following figures indicate possible levels of production of fuel and energy (probably for the year 1990) for the optimal and intermediary variants of the scenario:

	Optimal	*Intermediary*
Coal (million m.t.)	1,100	1,300
Natural gas (billion m^3)	1,100	900
Crude oil (million m.t.)	900	850
Nuclear energy (billion kwh)	700	650

In the example the favored variant (namely, the intermediary variant) gives coal a greater role than in the optimal variant, and nuclear energy's share in total energy production is reduced. The intermediary variant also reduces requirements for ferrous metals in comparison with the optimal variant.* As an example of the effect that a variant can have on other economic branches, the authors give the following figures indicating the additional amount of ferrous metals required to gain 100 million tons of standard fuel from increased production of natural gas and crude oil in comparison with strip-mined coal (in percentages):

	Oil	*Gas*
Pig iron	100%	270%
Steel	90–100	280
Rolled steel	100	290
Pipe	500–600	1,800–1,900

The preferred intermediary variant stresses production of coal because, the authors calculate, production of additional amounts of coal is easier to achieve and is less costly in the time period covered by the model than any other energy source. The variant therefore was felt to be less risky than the other two and more flexible, although more costly than the optimal variant. Both variants are now unreasonable. Coal and oil output have both peaked at well below targeted levels. Natural gas output is increasing but is still far from targeted levels. However, the targets are illustrative.

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*It is interesting that the authors emphasized this consideration in their analysis, which was published in 1974 when production of ferrous metals was still rising. Production of iron, steel, and rolled ferrous products peaked in 1978 and fell below the 1978 figures in 1979, 1980, and 1981(18).

Makarov (1980). In 1980 further modeling work by Makarov was reported in an *Izvestiya* of the USSR Academy of Sciences(19). This effort appears to be related to the previous work by Melentyev and Makarov, described just above. The lack of quantitative data and the omission of years beyond 1975 or 1980 from graphs, coupled with the implied magnitude of the effort, suggest that the paper describes an official forecasting project.

Makarov has undertaken to make a long-range forecast of fuel and energy production and consumption that appears to run from 1955 through 1975 or 1980 and out to an unspecified future date, probably 2015–2020. The projections were obtained from a dynamic input-output (I-O) model developed earlier by N. F. Shatylov and M. A. Gershenzon(20). The model consists of twenty-six sectors of the economy and four geographic regions. Its objective function (GNP) is maximized, subject to employment constraints. The 1968 I-O table is the base. (It is not known why the 1973 Soviet I-O table was not used.) Official economic statistics from 1968 through all subsequent available years and projections of statistics through the year 2000 formed the basis for modifying the initial I-O table for each year projected. The criterion of optimality is the minimization of discounted total expenditures on energy development in the period under consideration, adjusted for expected price changes. An important result from our point of view is the expectation that many of the R&D programs described in this book, namely, nuclear electrification (chapter 3), enhanced oil recovery and new forms of gas transport (chapter 4), UHV electrical power transmission out of the eastern regions of the USSR (chapter 6), and coal conversion, especially coal liquefaction (chapter 5), are projected to account for over one-half of the growth in energy production to be achieved by the year 2000.

The proposed strategy related to specific primary fuel developments is as follows. The share of hydrocarbons (crude oil and natural gas) in national energy production will grow slightly through the year 2000 but will fall drastically after that, declining to about the

1955 share (roughly 20 percent) by 2015 or 2020.* Oil production is expected to peak at the end of the 1980s—perhaps an overly optimistic projection considering the decline in oil production in 1984—causing problems with demand for liquid fuels in the USSR as well as the CMEA countries in Eastern Europe. Makarov states, however, that demand for liquid fuel can be satisfied and that there is a good possibility of doing so if timely and large enough investment is made in such measures as converting the truck fleet to diesel fuel, sharp increase in the depth of petroleum refining, liquefaction of coal and oil shale, and expansion of the use of electricity. (Given the slow growth of the Soviet economy at present, one may wonder if such investments can be forthcoming.) Oil's share will fall drastically after the year 2000. Natural gas is to be substituted for oil in boilers at electric power stations and industrial plants. Natural gas's share in the energy balance will rise slightly through the year 2000 and then fall slightly by 2015–2020.

Nuclear electrification will represent the fastest-growing energy source in the projection period. Starting from an insignificant share in 1975, Makarov projects an increase in its share to 10 percent of primary energy production by the year 2000 and a doubling of the share in the following fifteen to twenty years. The use of nuclear power for cogeneration of heat and electricity is also projected to rise sharply.

Coal's share is expected to decline slightly in the years ahead and to stabilize through the end of the century. After the year 2000, according to Makarov, an increase in its share will be unavoidable and will be achieved in part through the liquefaction of coal and UHV power transmission from the eastern regions of the country, notably from the Kansk-Achinsk Basin. The volume of coal being shipped from the Kuzbass to the Center is projected to peak in the late 1980s.

These results generally seem to be in line with Makarov's previous forecasts that were given above. The major trends in Soviet energy production are candidly described, although his projections of coal's ability to substitute for oil and natural gas in the next century may be overly optimistic.

*Makarov is not merely predicting; he is guiding the planners. Like all Soviet economists, he uses optimization techniques for forecasting, whereas Western economists would use econometric techniques.

Models of specific energy resources

Makarov, Makarova, Vigdorchik, et al. (1970). Results of a 1969–70 effort to model the role of nuclear power and heat generation in the Soviet economy were reported in the journal *Atomnaya energiya* in 1972. The effort was headed by Makarov and included researchers from four unidentified organizations. Melentyev provided scientific guidance to the group(21). The time frame for the projection covered the period before widespread introduction of breeder reactors but was otherwise undefined. The forecasting procedure incorporates a method previously worked out by Makarov related to the analysis of the zone of uncertainty in the optimal growth of the USSR's power system(22). The model covers the development of the fuel production and transport sector, the development of the unified power distribution system, and the main energy consumers. The model includes 250 constraints and 700 variables. (The model appears to use average values rather than marginal values.) Forecasts were made using one hundred scenarios of economic indicators and fifty scenarios for the energy factors.

Makarov's results regarding the economically optimal pace of growth of nuclear power are (1) nuclear power should account for 10–12 percent of total energy output by the end of the forecast period; (2) the share of coal in total energy output should fall to around 20 percent;* (3) nuclear power plants should begin to replace mal power stations, especially those burning Donets coal; (4) most gas- and oil-burning thermal stations should be designed for peak-load operation.

On a regional basis, nuclear power will be cheaper than fossil-fuel-based power in the European USSR and the Urals, but not in Siberia. Nuclear power capacity added during the last decade of the forecast period will account for 70 percent of total additions in the European USSR. (See also the related discussion in chapter 3.)

The "optimal" strategy selected for implementation by Makarov et al. is considered by them to be a moderate strategy wherein only 65 to 75 percent of the economically optimal nuclear power capacity should be built. In the "optimal" strategy, therefore, nuclear power will account for 7 to 8 percent of total energy output by the end of the forecast period. This seems to be a reasonable goal.

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*Cheap Siberian coal in the model is the chief competitor to nuclear power whether shipped to the European USSR by rail or by wire.

Koryakin et al. (1974). A June 1974 article in the journal *Atomnaya energiya* describes a modeling exercise with the goal of optimizing the role of nuclear power within the fuel and energy balance(23). The authors used a system consisting of the following:

Models for determining the structure of nuclear power plants. The models are based on linear programming and cover a 30- to 35-year forecast period. Over four hundred variables are used.

Models for predicting the structure of nuclear power stations in CMEA. The models are based on linear programming and include 180 variables.

Models for optimizing the fuel supply system for nuclear power generation. The models were based on nonlinear techniques and included up to 2,500 variables.

A model for estimating the role of nuclear power in the fuel and energy complex.

A model of fuel and energy balance developed by the Siberian Power Engineering Institute. The model is linear and includes 700 variables.

Models to determine the design parameters of nuclear power stations.

The authors conclude, on the basis of their modeling exercise, that nuclear power is economically feasible in a large part of the European USSR extending to the Urals and even into the western Kazakh SSR. The authors also indicate that nuclear power plants should, for maximum efficiency, be built from west to east (i.e., from the European USSR toward the Urals and Siberia). The authors also conclude that it may be rational to restrict the use of Kansk-Achinsk coal to Siberia. (This last point runs counter to the projections of Makarov [1980] described on page 293.)

Regional energy models

Makarov (1979). Efforts by Makarov to forecast the role of Siberia in fuel and energy production were published in 1979 in the journal *Ekonomika i matematicheskiye metody*(24). The results are based on the use of a dynamic model of the development of the fuel-energy complex that is divided into three geographical areas. The economy is divided into sectors producing twenty-five types of nonenergy products. Foreign trade in these products plus fuel also is incorporated into the model. The model itself is described in a 1976 monograph by G. Ye. Tkachenko(25).

According to Makarov, repeated modeling efforts have pointed to a few basic trends in the development of the Soviet fuel and energy complex. The most important appears to be the shift of energy production eastward with a resulting growth in the importance of transportation. In fact, Makarov says, one should now begin to speak of a "transport and energy complex" instead of a "fuel and energy complex"(24). The eastward shift will result in roughly one half of energy demand in the European USSR being met with eastern fuel and energy by the "end of the forecast period" (presumably the period 2015–2020), compared with roughly one quarter at the beginning of the period (1955–1960).

Since the growing importance of transport will lead to greater requirements for investment resources, Makarov emphasizes the need (1) to "rationalize" the productive structure of the fuel and energy complex and the location of energy consumers and (2) to accelerate technical progress in energy-related areas in order to minimize costs. Regarding the improvement of the productive structure, Makarov indicates that the following strategy seems the most expedient and feasible at present: (1) assimilation of the West Siberian oil and gas region, (2) creation of the Kansk-Achinsk Fuel and Energy Complex (KATEK) and development of the Kuzbass, (3) development of nuclear electrification up to its economically justifiable limits, and (4) creation of an Ekibastuz Coal and Energy Complex. (Note the similarity of results obtained here with those reported by Vigdorchik, Makarov, et al. [1972][16].)

Golovin, Kitaygorodskiy, and Faynshteyn (1979). This modeling effort represents an attempt, according to the authors, to fill a gap in existing modeling work wherein the costs of development of oil and gas fields are ignored(26). The authors have modeled the dynamics and economics of gas field development using the North Tyumen (Western Siberian) region as a case study. The modeling work was carried out at the Siberian Power Engineering Institute using packaged programs containing 271 equations and 1,238 variables. The task involved the development of a conditional function of probability distributions for the total growth in reserves of gas in the region in relation to the volume of investment in prospecting. A computerized model imitating prospecting work based on the Monte Carlo method was developed.*

The results of the effort are: (1) the most important factor in gas field development is the capital investment constraint for extraction; (2) increases in the *zamykayushchiye zatraty* for North Tyumen gas have the effects of intensifying the methods of extraction (more expensive, but faster methods would be used) and speeding the transfer of reserves from the "prospective" to the "industrial" category; (3) a shift from a higher to lower (or vice versa) level of assurance of transfer of reserves to the industrial category has little effect on the dynamics of extraction in the first five-year periods of the forecast period.

Models of Particular Technologies

The Soviets are now devoting a considerable effort to the use of mathematic modeling to optimize the design of particular pieces of hardware, such as nuclear reactors and power machinery. We should note here especially that the new Institute of Problems of Modeling in Power Engineering, Kiev, of the Ukrainian Academy of Sciences will, among other activities, be modeling the design of nuclear power stations and their constituent technologies. Since this particular application of modeling is somewhat tangential to the main concern of this chapter, we have merely listed some of the recent representative studies as references (27) to (31) at the end of the chapter.

Key Facilities and Persons

The development of the theory and methods for optimizing (and forecasting) the energy sector has been under the direction of the Academy's Scientific Council for Comprehensive Problems of Power Engineering since 1971(32). The lead research coordinator is the Siberian Power Engineering Institute (SEI), Irkutsk, of the SO AN SSSR. SEI coordinates the activities of roughly twenty-five organizations in the AN SSSR; the Academies of the Latvian, Lithuanian, Estonian,

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*The Monte Carlo method gives approximate solutions to mathematical problems using random sampling.

Belorussian, and Ukrainian SSR; the Far East Center and the Kola and Komi Branches of the AN SSSR; and various ministries and agencies, as well as higher schools(32). Gosplan's VNIIKTEP (see chapter 2) probably plays a major role in work related to computer-based energy models for planning, a topic not considered here(33).

SEI has been engaged in energy modeling since the early 1960s, and Makarov and Melentyev were once associated with this institute.* (Melentyev was the director of SEI between 1963 and 1970.) Other prominent energy modeling experts at SEI include L. S. Belyayev and Yu. D. Kononov. Additional works from SEI not elsewhere cited are listed as references (34) through (40) at the end of this chapter. (See also appendix E for details on SEI.)

A second major modeling center is the Academy's Institute of High Temperatures (IVT) in Moscow. The most prominent energy-modeling authorities there are, again, Melentyev and Makarov. According to Makarov, IVT recently has been developing a model for forecasting energy consumption based on a statistical description of the component trends in consumption in the form of a system of interrelated dependencies(19).

A third important center is the recently created Institute of Problems of Modeling in Power Engineering, Kiev, of the Ukrainian Academy of Sciences, which was mentioned above. This institute, which is directed by G. Ye. Pukhov, an academician of the Ukrainian Academy, was created in 1981 to assist in the development of the electrical power industry in the Ukraine. The institute is engaged in the application of mathematical models to the design of nuclear power stations and will coordinate all activity in the republic involving power engineering and modeling(41).

Other institutes known to have been involved in energy-modeling work include Leningrad Polytechnical Institute imeni Kalinin, MVSSO RSFSR; "Elektrosetproyekt" Institute; Institute of Thermal Physics and Electrophysics, Academy of Sciences of the Estonian SSR; Main Computer Center of Gosplan USSR; All-Union Scientific Research Institute of the Petroleum Industry (VNIINP); and All-Union Scientific Research Institute for the Organization, Management, and Economics of the Oil and Gas Industry (VNIIOENG). Other prominent personalites include L. E. Vayk, L. Ye. Varshavskiy, L. D. Krivorutskiy, A. S. Makarova, M. Kazanov, L. A. Krumm, and V. A. Venikov.

* See p. 289 above concerning Makarov's continuing affiliation with SEI.

Evaluation

From the limited amount of information available on Soviet modeling efforts, it is not possible to offer a complete evaluation of these efforts. However, it is possible to point out some apparent strengths and weaknesses of these models.

On the plus side, it is clear that Soviet analysts are asking many of the right questions and taking account of important factors. Modelers have attempted to simulate the behavior of the important energy sectors and to take account of the relationships between energy and other sectors of the economy. They are concerned about comparing the costs of energy from various sources, both at the production site and at the point of consumption (after transportation costs have been added in). They are also interested in the demands that energy development projects will place on other sectors of the economy (e.g., on the iron and steel industry, machine building, and the railroads).

The descriptions of models show impressive activity in a number of respects. Various analysts are using techniques such as linear programming, nonlinear programming, and input-output analysis. Large numbers of equations and variables—thousands, in some cases—are being included in models and "shadow prices" are being computed to compare the marginal costs of energy from various combinations of fuels, locations, and time. In addition, those who are planning modeling efforts have shown a practical side to their efforts by attempting to take account of the risks attached to some options rather than simply settling for the variant that minimizes total energy costs.

Some aspects of Soviet modeling efforts cannot be evaluated at all well. Western attempts to model the Soviet economy have run into a number of difficulties.* The data are often defective because of ambiguous definitions of the concepts being measured and incentives for reporters of data (e.g., factory managers) to misstate figures in order to secure bonuses or other rewards. Data sample sizes frequently have been small, reducing the reliability of equations estimated by econometric techniques. Only by knowing more details about the data being used to estimate coefficients and about the actual equations estimated, including diagnostic statistics (t-statistics, coefficients of determination, standard errors of estimated regression coefficients), can one judge the degree of reliability of the individual equations that comprise the model. Such information typically does not appear in published accounts of modeling efforts.

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*One of the most ambitious recent efforts was the development of SOVMOD I(42).

On the negative side, there are a number of reasons for concern about the reliability of models and the results they produce. As noted above, Western analysts have been concerned for a number of years about the quality of published Soviet statistics. Soviet modelers may have access to more information than is published in standard statistical handbooks such as *Narodnoye khozyaystvo SSSR (National Economy of the USSR)*, but it is not clear that the quality of such unpublished information will be any higher than that of published data.

There are also likely to be problems involved in converting units of energy into a standard form. In studying energy flows in general, it is useful to have a common physical or financial measure. The Soviets commonly convert crude oil, natural gas, coal, and other energy materials into metric tons of "standard fuel" on the basis of the heat content of those sources.* Such a measure is convenient but does not take account of differences in the cost and ease of transporting and using different fuels. (As an example, it is well known that the cost of transporting a given number of BTUs in the form of natural gas is higher than for an equivalent number of BTUs in the form of crude oil.) Such qualitative differences are not reflected in the simple BTU conversion factors.

The alternative to using units of standard fuel is to use the money value of fuels, attempting, for example, to minimize the total cost of energy needed to support a given level of GNP. However, there are many reasons to doubt the reliability of prices that would be used to convert fuels into monetary terms. As a result, they reflect very imperfectly either the cost of providing a particular fuel or the usefulness to industry and society in general of that fuel at any particular time.**

The upshot is that the use of improper factors to convert various fuels into a common physical or monetary measure may distort the relative cost or usefulness of a particular fuel and result in an "optimal" model variant that is not really optimal. As an example, for many years the official wholesale price of coal was lower than the average cost of producing coal. During that period a modeling exercise that weighted fuels on a monetary basis probably would have led to recommendations to use more coal than would have been appropriate for optimization of the Soviet economy. Today, the strict use of thermal conversion coefficients would probably underweight the environmental advantages of natural gas over coal, leading to excessive use of coal.

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*One ton of standard fuel has a heat content of seven gigacalories or 27.8 million BTU(43).

**Interregional transport cost models regularly use differential coefficients to account for differences in fuel types(44). This technique could be used to bypass these problems.

Whether or not these defects of Soviet modeling are serious will depend on how the modeling results are used. If the results are used for detailed planning without close scrutiny of the optimal variants, problems are likely to arise. On the other hand, if the models are used to produce general recommendations that then are studied carefully, the risks should be lower. (In fact, this seems to be the case.) As an example, numerous model results suggest that nuclear plants should be built in the west first and gradually spread toward the east. This appears to be a very sensible recommendation, but more detailed analysis will be needed to determine just how far east nuclear plants should be located.

It is worth noting that Soviet planners are attempting to model the cost of providing energy using technologies that have been proposed but not yet developed. As an example, the Department of Power and Electrification of Gosplan USSR has attempted to compare the delivered cost of electricity shipped from Ekibastuz and Kansk-Achinsk via 1,500-kv and 2,250-kv DC lines, even though neither of these transmission technologies has been proven to be technically or economically feasible(45). Such modeling can provide a valuable input to the planning of R&D efforts, but obviously the results should be used with caution.

Finally, it cannot be assumed that the political leaders of the Soviet Union will choose to follow the recommendations of energy modelers—no matter how skilled and insightful they may be. Eric Jones has argued that energy development in the Soviet Union is a highly political topic (as it is in the United States), with various political figures, ministries, regions, and even scientific research institutes pushing their pet projects and jockeying for advantage(46). A recent review of Soviet R&D on coal and oil shale revealed a number of instances of the intrusion of politics into what should be rational, scientific decisions(47). However, it appears that sophisticated projection methods are more and more finding application in government planning agencies and should not be considered mere academic exercises.

In summary, a number of modeling efforts are under way in the Soviet Union, and these activities should aid planners in formulating economically rational plans for energy R&D and for the development of energy resources. Although there are some problems that are likely to arise in modeling with Soviet data, the use of models and other mathematical methods should improve the planning process in the Soviet Union if the results of these methods are used in a prudent manner and with due regard for their limitations.

Chapter 9 Hypotheses about a Rational Strategy for Development of Soviet Energy

The purposes of this section are to assemble the major points that emerge from the preceding review of Soviet R&D efforts in the energy area, to develop hypotheses about the future course of Soviet energy R&D, and to derive the implications of these R&D efforts for the future production and consumption of energy in the Soviet Union.

Our review has not attempted to examine all phases of Soviet energy R&D but instead has focused on those programs that support one or more of the following seven basic goals of Soviet energy development:

(1)Increase nuclear electrification.
(2)Increase recovery of oil.
(3)Increase output of Arctic gas.
(4)Increase exploitation of Eastern coal.
(5)Increase efficiency of energy utilization.
(6)Introduce alternate energy technologies to meet local needs.
(7)Achieve an optimum mix of energy technologies to meet developing needs.

It is therefore fitting that this section should work within this framework. In order to further focus this summary review on the most important R&D efforts, the discussion is targeted on those programs that seem likely to (1) result in commercial applications by 1995 and (2) seem likely to have a substantial impact on Soviet production or consumption of energy by that year. By "substantial impact" we mean a change of more than 1 percent in total energy supply or demand in the year in question. These impact assessments are heavily subjective in nature.

The specific year 1995 is an appropriate cutoff because it probably is the final year in any recent Soviet perspective plans and because it is difficult to project R&D developments for much more than a decade. For convenience the review that follows is organized according to the seven goals listed above.

Energy R&D Programs Likely to Have a Substantial Impact by 1995

Goal 1: Increase Nuclear Electrification

Conventional fission reactors now are being operated for purposes of electric power generation, and more will be installed as they are produced. Once the long-delayed "Atommash" Production Association becomes fully operational (before 1995), the Soviet Union will begin an era of series production of 1,000-MW nuclear reactors that should be turned out at the rate of eight per year. Conventional reactors now are being used for district heating purposes and should find wider application over the next decade.

The Soviets already have commercial fast reactors operating at Shevchenko and Beloyarskiy and could complete several additional breeders before 1995 (e.g., the BN-800). At the beginning of 1983 fast reactors accounted for 4 percent of Soviet nuclear capacity. However this share is likely to be smaller in 1990 even if the BN-800 comes on line. R&D on fusion reactors is continuing but is unlikely to be applied commercially before the turn of the century.

Goal 2: Increase Recovery of Oil

As Soviet exploration for and production of petroleum shifts to increasingly hostile environments and deeper strata, weaknesses in Soviet drilling technology have become evident. The turbodrill and Soviet drill bits have performed adequately in shallow drillings but are less and less suitable as well depths increase. A number of efforts are underway to improve the turbodrill, drill bits, tool joints, and drill pipe casing. No revolutionary changes seem likely in Soviet technology, and there is no sign of a large-scale swing from turbodrilling to rotary drilling. Instead, what seems likely is a continual series of incremental improvements in drilling technology, with designers learning to adapt to the idiosyncrasies of existing Soviet equipment and the weaknesses of Soviet metallurgy. This incremental approach will bring slow improvements in the productivity of drilling equipment, but the gains in the capabilities of equipment may not keep pace with the challenges of the exploration and production frontier.

Enhanced recovery techniques will allow the Soviets to raise more oil from traditional fields in the western part of the country that are close to consumers and well equipped with supporting physical infrastructure (e.g., railroads and pipelines). Increasing efforts are being put into enhanced recovery R&D, and substantial results should be evident during the coming decade. It will be surprising, nevertheless, if Soviet oil production does not peak out before 1990. It may have already.

Goal 3: Increase Output of Arctic Gas

It is generally agreed that the Soviet Union has tremendous reserves of natural gas in Western Siberia. Success in exploiting these reserves depends in part on drilling technology, but even more so on Arctic pipeline technology. Soviet pipelines are not likely to reach diameters much beyond 1,420 mm, but efforts are under way to increase their throughput capacities by raising operating pressures to as much as 120 atmospheres, adding additional compressor stations, and cooling the gas. The Paton Electrowelding Institute has developed a laminated pipe that is central to these efforts to raise operating pressures, and development of production seems to be proceeding in a satisfactory manner. R&D programs also are aimed at improving the cold resistance of steel, the speed and quality of welding, the design of pipeline supports, and the power and reliability of compressors. The development of the 25-MW GTN-25 compressor is of particular note here.

At this point in time the problem of transporting Arctic gas to the European USSR appears to be more of a production problem than an R&D problem. The needed innovations in pipeline technology have been achieved or appear imminent. Success in taking advantage of these innovations will depend on the ability and willingness of the metallurgical, machine-building, and construction ministries to supply the goods and services needed by the Ministry for the Construction of Oil and Gas Industry Enterprises.

These improvements in traditional gas pipeline technology are likely to have a substantial impact on energy supplies well before 1990, but more radical measures such as liquefaction of gas or use of capsule pipelines for long-distance transport seem unlikely to be commercial before 1995.

Goal 4: Increase Exploitation of Eastern Coal

Eastern coal will grow in importance as an energy source for the industrial regions of the central USSR and the Urals as older coal-producing areas such as the Donets Basin become depleted. The eastern coal basins capable of providing the European USSR with fuel under present technical and economic conditions are the Kansk-Achinsk, Ekibastuz, and Kuznetsk basins. All other basins now being exploited are of local or regional significance.

Ekibastuz and Kuznetsk coals can be shipped to the Urals and the Center by rail and still be competitive at point of consumption with other fuels. When the 1,150-kv AC line between Ekibastuz and the Center is completed (construction is now under way), electricity generated from Ekibastuz coal will be competitive in the Center with electricity transmitted from any likely outside source (but not local nuclear plants).

Kansk-Achinsk coal, on the other hand, has no ready market, lying between the Ekibastuz and Kuznetsk basins to the west and the Irkutsk and Trans-Baykal basins on the east. Rail shipment of Kansk-Achinsk coal requires not only an enormous investment in track and rolling stock but would require construction of special coal treatment plants to raise the caloric content of the coal. Transmission of Kansk-Achinsk coal as electricity must await further development of UHV or cryogenic power transmission technology.

The Kansk-Achinsk Basin does represent a significant share of the strip-mineable coal in the USSR—coal that will be exploited one way or another. Before 1990 Kansk-Achinsk coal will be developed by creation of KATEK, with the siting of energy-intensive industries in the Kansk-Achinsk area. Kansk-Achinsk coal also can be transported by rail to surrounding areas of Krasnoyarsk Kray and can be substituted for Kuznetsk coal in power generation in Siberia. Kuznetsk coal then could be transported to the Urals or the Center. Both of these options have the support of the USSR Gosplan.

Two other options for exploiting Kansk-Achinsk coal—liquefaction and gasification—are not likely to be commercialized before 1995.

Slurry pipeline transport is advocated as an efficient and less capital-intensive means of transporting Kansk-Achinsk coal, but container pipelines are being seriously considered only for short-haul transport. Coal slurry pipelines would require massive investment in diverting the waters of several Siberian rivers to Kansk-Achinsk. All things considered, pipeline transport of Kansk-Achinsk coal probably is not economically rational.

Until recently, Soviet energy modelers believed that it was relatively easy to increase coal production and that flexibility in energy policy could be achieved by increased reliance on coal. The Siberian coal deposits thus were viewed in part as stores of reserve energy to be developed quickly in case oil or gas production were constrained by unforeseen circumstances. In view of the declines in coal production that occurred after 1978 Soviet planners are more skeptical about coal. Coal's share in the energy balance is expected to decline slightly and then stabilize through the end of the century.

Goal 5: Increase the Efficiency of Energy Utilization

MHD power plants may go into commercial use before 1990, but it is unlikely that they will have a substantial impact until after the year 2000. Ultra-high-voltage power transmission R&D has progressed to a point where 1,150-kv AC lines are likely to become operational before 1990, but it is not clear that 1,500-kv lines and higher-voltage lines can become commercial before 1995. If successful, ultra-high-voltage power transmission will be used primarily to move electricity from Siberia to the Urals and the Center and will promote the development of Siberian coal deposits. Superconducting power transmission is unlikely to be commercial before 1995, if at all. Pumped-storage plants are under construction, and some additional ones should be in operation by 1990.

Many programs are under way throughout the Soviet economy to increase the efficiency of energy utilization in industry. These programs are likely to result in a steady commercialization of innovations in the use of energy and, collectively, should result in substantial energy savings.

Goal 6: Introduce Alternate Energy Technologies to Meet Local Needs

The most important programs directed at this goal are those concerned with solar, wind, and geothermal energy. Production of electricity from wind power is now technically feasible and is economically attractive in remote areas served by small diesel power plants. Now that NPO "Tsiklon" has been established, the production and installation of wind-powered electric generators may become institutionalized, leading to widespread adoption of this technology in sparsely populated areas. However, some Soviet writers are dissatisfied with progress in this area.

Solar energy now is reasonably attractive as a means of heating water and buildings and for various agricultural applications, but it is not yet economically appealing as a means of generating electricity on a large scale, although an R&D breakthrough could come in the next ten years.

Geothermal energy can be used for electric power generation in a number of areas of the Soviet Union, but it is most likely to find application in heating of greenhouses and buildings between now and 1995.

Solar, wind, and geothermal energy technologies offer a means of replacing diesel fuel in remote areas of the country and a means of raising the living standards of ethnic minorities. Although no one of these energy sources seems likely to have a significant impact on the Soviet energy scene, the three taken together could account for several percent of total Soviet energy production by 1990. Production of oil shale and peat will continue, but those fuels will be of regional significance at most.

Goal 7: Achieve an Optimum Mix of Energy Technologies to Meet Developing Needs

Soviet planners have been applying modeling techniques to the planning of energy development since at least the late 1950s. These models have become quite sophisticated and complex and are being used to examine both alternative approaches to producing and transporting energy in the Soviet Union and the relationships between energy sectors and the rest of the Soviet economy. The major known weak link in such optimization efforts is the Soviet system of prices that reflects quite imperfectly both the costs of producing and transporting energy source materials and the convenience of various energy sources for consumers. Nevertheless, if those models are used with caution they should improve the process of optimizing the mix of energy technologies as the Soviet economy evolves. A major energy modeling effort completed roughly four years ago places great emphasis on the development of new energy technologies, including especially nuclear electrification, enhanced petroleum recovery, new forms of gas transport, and coal conversion—programs that have been treated in detail in this study.

Energy R&D Strategy in the Soviet Union

Before sketching out our vision of the Soviet strategy for energy R&D, it is useful to make some observations about Soviet energy in general and Soviet energy R&D in particular.

First, funding of R&D on energy can be seen as a means of generating new options for the production, transportation, and consumption of energy. The energy situation in the Soviet Union is evolving in a dynamic fashion as the economy expands and changes structurally, fossil fuel supplies become depleted in certain regions, and world prices for petroleum change. The Soviet leadership must respond to these changes over time and would like to have a larger number of choices and more economically attractive options in its portfolio. Investment in energy R&D is one way to create more options.

Second, Soviet willingness to pursue new options will depend, in part, on the willingness of the leadership to assume risks. The Soviet leadership under Brezhnev, Andropov, and Chernenko was characterized as bureaucratic, conservative, and cautious. To date, we see no *fundamental* change under Gorbachev. In the area of energy we find this conservatism to be much less pronounced in R&D decisions than in decisions on implementation of new production or transportation technologies. The leadership has shown a willingness to encourage and fund energy R&D on a wide variety of topics, many of which are high-risk ventures that cannot be expected to become commercial for decades (e.g., fusion research, superconducting power transmission, and capsule pipeline transport). One manifestation of this has been an almost reckless willingness by the Soviets to build demonstration plants before processes are fully worked out, counting on scientists and engineers to debug the plants and to make them work. However, when it comes to a decision to go commercial and put a new production or transport technology in place on a large scale, we expect the leadership to be much more conservative. This is because individual members of the leadership hierarchy do not find it personally rewarding to strongly back risky propositions that could fail and damage their standing in the ruling oligarchy.

Finally, it is worth noting again the importance of geography in the Soviet energy context. Most of the population and industry of the USSR are located west of the Ural Mountains, while most of the reserves of fossil fuels are east of the Urals. This situation is unlikely to change in the next several decades, barring a catastrophic upheaval such as nuclear war. As a result, transportation costs must be an important consideration in the decision-making process.

With these thoughts in mind, let us attempt to sketch out the energy R&D strategy that emerges from the program reviews in this book.

First, a number of R&D programs appear to be motivated, at least in part, by a desire for the country to continue to export petroleum in order to take advantage of high prices for crude oil and earn much-needed foreign exchange.

Crude oil is being treated as a scarce resource that should not be used domestically if other fuels can be substituted for it without unreasonable difficulty. Natural gas from the Arctic regions of Western Siberia is seen as a substitute in many existing installations, while coal, nuclear energy, and natural gas are seen as the appropriate energy sources for many new installations (especially electric power plants). One sign of this concern is a program to convert thousands of public motor vehicles to the use of natural gas. Programs to use wind, solar, and geothermal energy as sources for electric power production are motivated in part by a desire to displace the diesel power plants that generate electricity for many remote and sparsely populated areas.

Efforts also are under way to increase crude oil production or, at the least, keep it from falling sharply. Modern geological prospecting techniques (e.g., geochemical prospecting) are being pushed to aid in the discovery of new petroleum reserves, and incremental improvements in drilling technology are being made to increase the productivity of Soviet drilling equipment. R&D on enhanced recovery also is under way and shows promise of having a substantial impact on the production of oil. Soviet petroleum production technology is generally behind that of the West, and the Soviets clearly could benefit from further infusions of Western technology or continued indigenous R&D.

A second part of Soviet energy R&D strategy is a push to develop nuclear energy in the area west of the Urals in order to reduce the need for shipment of fossil fuels from Siberia. Nuclear reactors now are being used primarily for production of electricity, but the Soviets already have plans to use them for large-scale district heating. There is widespread acceptance of the rule of thumb that nuclear installations should be built in the west and spread east as capacity permits. The rate of expansion of nuclear energy is being limited by Soviet capacity to build nuclear power plants and by apparent concern about uranium reserves. The latter factor has motivated Soviet interest in the breeder reactor and fusion power.

Given Soviet desires to reserve part of crude oil production for export and given the inability of nuclear power to expand as fast as desired, Soviet authorities must turn to other energy sources to fill the growing needs of the USSR west of the Urals. The logical choices are natural gas from the northwestern part of Siberia and coal from the Kuznetsk, Ekibastuz, and Kansk-Achinsk basins. As noted earlier, we see no insurmountable technological problems that will block a large-scale expansion of production and transport of gas from Siberia or coal from the Ekibastuz and Kuznetsk basins. But, given the poor qualities of Kansk-Achinsk coal and the great distances that it would have to be transported to reach the Urals or the Center, it is not clear how this resource will be used in the near future.

Finally, the Soviet Union, like other industrial nations around the world, has become very conscious of the finite nature of many energy source materials and has become concerned that energy not be wasted. Large numbers of R&D efforts are under way to improve the efficiency of energy utilization. A few, such as MHD power generation and superconducting power transmission, have received great attention. But, in the aggregate, the many smaller initiatives spread throughout industry and other sectors of the economy are likely to have a much larger impact. We expect to see a continual series of improvements in the efficiency of energy utilization that will eventually result in a measurable increase in the amount of GNP produced per unit of energy consumed. Because of the long service life of capital equipment in the Soviet Union, such changes may not be noticeable in the aggregate for a matter of years.

A Description and Assessment of the Energy Strategy Implied by Soviet R&D Efforts

The energy strategy that we see emerging from Soviet R&D efforts can be summarized as follows:

(1) Seek to continue exports of crude oil by maintaining production and reducing consumption of oil; expand exports of natural gas by increasing production and building gas pipelines to the West.
(2) Expand the use of nuclear power in the European USSR to reduce dependence on crude oil and to reduce expenditures on transporting Eastern coal and Arctic gas to the European USSR.
(3) Expand the use of Arctic gas and Siberian coal to fill the needs that cannot be met by nuclear power.
(4) Increase the efficiency of transport and utilization of energy in general.
(5) Develop solar, wind, and geothermal energy in remote, sparsely populated areas to conserve diesel fuel (and raise living standards of ethnic minorities).
(6) Create an expanded portfolio of technological options for dealing with energy needs in the future.
(7) Plan for a viable and low-cost supply of energy to the Soviet economy over time by mathematical modeling of energy options.

We believe that this strategy is internally coherent and is technically and economically rational for the most part, although selected R&D efforts may not be successful.

The Soviet Union has a large, well-staffed, and generally well-equipped R&D establishment available to support the energy strategy outlined above. The leading institutes involved in this strategy are listed in table 21. Of course, it is doubtful that all of the R&D options being sought by the leadership can be successfully developed through

Table 21 Key Organizations in Soviet Energy R&D

Institute of Atomic Energy imeni Kurchatov (IAE), Moscow	Nuclear power; MHD
Physical-Technical Institute, Sukhumi	Nuclear power
Physical-Energetics Institute, Obninsk	Nuclear power
Institute of High Temperatures (IVT)	MHD
All-Union Scientific Research Institute of Drilling Equipment (VNIIBT)	Drilling equipment; oil rigs
All-Union Scientific Research Institute of Main Pipeline Construction (VNIIST), Moscow	Pipeline welding and construction; pipeline laying equipment; strength of metals
Central Boiler and Turbine Institute imeni Polzunov (TSKTI), Moscow	Fluidized-bed combustion; lignite-burning boilers
Siberian Energetics Institute (SEI), Irkutsk	Nuclear power; coal conversion; energy modeling
Institute of Fossil Fuels (IGI), Moscow	Drying, gasification, and liquefaction of coal; oil shale technology
NPO Tsiklon, Istra	Design, production, and installation of wind power units
All-Union Scientific Research Institute of Current Sources (VNIIT), Moscow	Solar energy
Physical-Technical Institute imeni Starodubtsev, Tashkent	Solar energy
Physical-Technical Institute, Ashkabad	Solar energy
State Power Engineering Institute imeni Krzhizhanovskiy (ENIN), Moscow	Container pipelines; coal conversion; solar energy; MHD; superconducting power transmission
All-Union Electrotechnical Institute Imeni Lenin (VEI), Moscow	UHV and superconducting power transmission
Leningrad Scientific Research Institute of Direct Current Sources	UHV power transmission
Laboratory of Very High Voltages, Leningrad	UHV power transmission

the demonstration stage, but we believe that enough can be brought to that point to allow the leadership to pursue its most important energy goals.

The chief weaknesses of the Soviet system in pursuing this energy strategy probably lie with the production ministries rather than with the R&D establishment. As examples, the designers of drilling equipment have spent years trying to adapt to the deficiencies of the metallurgical industries that have produced low-quality casing and drill pipe. Heat treatment techniques are available now for Arctic pipelines, but there are difficulties in securing treated pipe from the producers. NPO Tsiklon has designed workable wind generators but has experienced difficulties in obtaining electrical equipment that it needs for its wind devices. The long delays in finishing the ETKh-175 coal pyrolysis installation in the Kansk-Achinsk Basin have been caused more by bureaucratic problems of coordinating a large construction project than by technical problems. Numerous similar examples could be cited.

The Soviet Union may not find it easy to pay for the energy strategy outlined above. Large-scale expansions of nuclear power, Arctic gas, and Siberian coal will place strains on the nation as a whole and on key sectors such as metallurgy and machine building. It is interesting to note that the energy cost of this strategy is likely to be high because some supporting industries—such as ferrous metallurgy, which supplies materials for pipelines—are enormous consumers of energy.

If this strategy succeeds, it will bring about changes in the energy economy of the Soviet Union, although it is unlikely that such an enormous energy system can change dramatically between now and 1990 or even the year 2000. The Soviet Union cannot afford to abandon any one energy source, nor can it create an entirely new one overnight. In addition, the present diversification of energy resources and the existence of significant transportation costs make it likely that part of the change in fuel shares will occur through expansion or contraction of the natural markets for particular fuels as relative production and transportation costs change over time.

In terms of shares in the total fuel-energy balance, it is likely that nuclear energy will expand substantially and that crude oil will level off and then decline as percentages of the total. Natural gas is likely to expand relative to oil and, perhaps, as a percentage of total fuel production. Except in the case of nuclear power, these changes are likely to amount to only a few percentage points between now and 1990, but they may be more dramatic during the last decade of this century. Coal is unlikely to increase its share until the next century.

Nuclear power will grow in significance in the European USSR, spreading from the west to the east, but should find little application beyond the Urals.

Production of Siberian gas will expand substantially, and this gas will be shipped to the Urals, to the Center, and to the West in higher-pressure pipelines but in gaseous form.

Siberian coal will be applied over a wider area of the country, although the exact extent of the market is difficult to predict. Kansk-Achinsk coal will probably be used to generate electric power in southwestern Siberia, and a complex of fuel-intensive industries is likely to grow up around it, but at present it seems unlikely that Kansk-Achinsk coal will have much impact outside of Siberia. Progress in UHV power transmission is a critical factor in determining the radius of influence of Kansk-Achinsk coal. Coal from the Ekibastuz and Kuznetsk basins is more likely to be transported (as coal or electricity) to the Urals and the Center.

We do not see an "either/or" choice between Siberian natural gas and Eastern coal. Both will be developed over the next decade or two. What is more difficult to predict is the boundary of indifference between the market zones for the two fuels.

It is clear that there are significant economic risks in developing Soviet energy resouces, but several factors will help to reduce these risks and aid planners in adapting to unforeseen changes. First, the application of modeling techniques will allow planners to simulate many future energy scenarios and, in doing so, avoid some of the worst mistakes that might conceivably occur. Mistakes will be made, and unanticipated changes in supply and demand are likely to occur from time to time. It is therefore worth noting that the Soviet Union has several ways of adapting to unforeseen changes in energy supply and demand.

First, the Unified Power System can be used to move a certain amount of electric power from one region to another in the event that imbalances develop between electricity supply and demand. In a broader sense, by reducing power generation in one region or from one fuel, and increasing that in another region or from another fuel, the UPS can be used to counter imbalances of not only power, but fuels as well.

Second, the natural gas trunk pipeline system is being expanded and integrated. The new pipelines coming out of the Urengoy area to the Center, including the export pipeline, will be linked with the existing system at several points. This integration will facilitate the routing of gas from one area to another. An important secondary benefit will be a reduction in the risk involved in meeting export obligations.

Third, Siberian coal is viewed as a reserve energy resource, the production of which can be increased quickly to counter fuel shortages in the economy. At the worst, additional coal can be mined in the Ekibastuz or Kuznetsk basins and shipped to other parts of the country by rail. Such a procedure might not be optimal in terms of costs, but it might be very sensible if it would avoid the temporary shutdown of a portion of the economy. Of course, the use of the UPS, the gas pipeline network, or Siberian coal to counter shortages presupposes the existence of some slack in the economy.

In conclusion, it is clear that the Soviet Union has an abundance of energy source materials and should be able to supply its own needs over the long run if it chooses to do so. The nation is at present in a state of transition in response to increased world prices for crude oil, its own changing perceptions of the cost and scarcity of traditional fuels, and some temporary domestic imbalances between energy supply and demand brought on by past mistakes in planning.

Based on our review of Soviet energy R&D activities, we believe that the Soviet Union has a coherent, technically feasible, and economically rational energy strategy for adapting to past changes and meeting the future needs of the nation for energy and foreign exchange. The Soviet R&D establishment should be capable of developing enough technical options to support this energy strategy. Soviet success in meeting national energy needs in the future will depend most of all on its willingness to devote the needed productive resources to this energy strategy and on the performance of key ministries such as those involved in metallurgy, machine building, and construction.

Appendix A Draft Main Directions Related to Energy for the Tenth FYP (1976–1980)

1. Main Directions for Selected Branches of the National Economy

a. Electrical Power Engineering

Provide, by 1980, for the [annual] production of 1,340–1,380 billion kwh of electric power. Put on-line at electric power stations capacities on the order of 67–70 thousand MW, including 13–15 thousand MW at nuclear power stations. Continue the construction of 4,000- to 6,000-MW thermal power stations with 500- and 800-MW power units and nuclear power stations with 1,000- to 1,500-MW reactors.

Provide for the wider use of inexpensive solid fuel for the production of electrical energy. Carry out the construction of large thermal power stations burning coal from the Ekibastuz and Kansk-Achinsk deposits.

In hydroelectricity, continue the equipping primarily of large hydraulic facilities, making it possible to comprehensively solve the tasks of the production of electric power, irrigation of land, supply of water to cities and industrial enterprises, development of shipping and fishing, and flood prevention.

Provide for the priority development of nuclear power engineering in the European USSR. Accelerate the construction and assimilation of fast-neutron reactors. Begin preparatory work on the use of nuclear power for heat generation.

Continue work on the formation of a unified power system in the country by uniting the power systems of Siberia and Central Asia with the European power system and by constructing 500-, 750-, and 1,150-kv main power transmission lines.

Provide for the improvement of the technical and economic indicators of the operation of power equipment, accelerate for this purpose the assimilation of variable-load 500-MW power-blocks and the construction of pumped-storage power stations and gas-turbine installations.

Reduce the specific fuel consumption at power stations by 1980 to 325–328 grams/kwh of output power.

Increase the productivity of labor in electric power engineering by 27–29 percent.

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b. The Petroleum Industry

By 1980, increase the extraction of crude oil, including gas condensate, to 620–640 million m.t.

Improve the use of natural resources of crude oil, increase the output of the strata, carry out scientific research and experimental-industrial work on the extraction of petroleum from bituminous rock.

Continue the technical reequipment of the branch, the comprehensive automation of technological processes, and the introduction of automated control systems at oil fields; by the end of the five-year plan increase the production of oil at these fields to not less than 85 percent of the overall volume of production.

Accelerate the introduction into operation of new petroleum deposits; widely use prefabricated modular construction units for the construction of facilities for the gathering, preparation, and transport of petroleum.

Raise the efficiency of drilling operations. Reduce by 25–30 percent the periods for constructing wells by increasing drilling speeds; by the introduction of all-purpose drilling rigs, new types of bits, bottom engines, drilling muds, high-strength casing and drill pipe; and by the improvement of the organization of work and the application of progressive methods of assimilating wells.

Accelerate the construction of gas-processing plants. Provide for the use of 43–45 billion m^3 of oil-associated gas by 1980.

Increase labor productivity in the oil industry by 28–30 percent.

c. The Petroleum Refining Industry

Increase the volume of primary oil refining by 25–30 percent. Ensure the improvement of the technology of petroleum refining, the introduction of new technological processes, effective catalysts, and progressive equipment.

Increase the production of high-octane gasolines, low-sulfur diesel and aviation fuels, and aromatic hydrocarbons by means of better refining of petroleum and increasing the share of secondary processes, and [increase] also the output of high-quality lubricants.

Shift to the construction of basically combined and enlarged technological installations. Ensure that the refining of oil is brought nearer to the regions of mass consumption of petroleum products.

Increase labor productivity in petroleum refining by 39–41 percent.

d. The Gas Industry

Achieve by 1980 the production of 400–435 billion m^3 of gas. Put roughly 35,000 km of gas pipelines into operation.

Comprehensively use oil-associated and natural gases, obtaining from them condensate, sulfur, helium, and other accompanying components.

Continue to construct underground gas reservoirs chiefly in the areas of heaviest energy demand; use for these goals depleted gas and oil fields to the greatest extent possible.

Develop and introduce progressive technical means and methods of extraction, transport, processing, and storage of gas and gas condensate, including [means and methods] for the conditions of the Far North. Provide for the construction of reliable highly productive operational wells using new methods for intensifying the flow of gas to the wellhead, automated modular installations for field gas preparation, gas pipelines with diameters of 1,420 mm and above with working pressures of not under 75 atmospheres, compressor stations with gas-pumping units of up to 25-MW capacity. Ensure the selection of the most economical routes for gas pipelines. Increase the effectiveness of gas pipeline operation by carrying out organizational and technical measures, and by increasing the number and capacity of compressor stations.

Continue the creation of a unified, automated gas supply system for the country.

Accelerate scientific research and experimental-design work on the creation of fundamentally new methods of transporting gas.

Increase the productivity of labor in the gas industry by 43–45 percent.

e. The Coal Industry

By 1980, increase the [annual] extraction of coal to 790–810 million m.t.

On a broad scale, improve the equipment and technology, thereby ensuring the acceleration of growth rates for the extraction of coal, increasing its quality, and further increasing branch efficiency.

Concentrate reconstruction and modernization work primarily at those mines and pits at which the application of progressive technology and new equipment will ensure the greatest growth in coal extraction, significantly increase the productivity of labor, and improve the technical and economic indicators.

Widely develop the surface mining of coal in the eastern regions of the country.

With the goal of significantly increasing the fuel and energy resources for the long term, accelerate the development of the South Yakutsk coal region, together with the development of existing coal basins—Donets, Kuznetsk, Karaganda, Pechora, and others. Begin work on the accelerated creation of the Kansk-Achinsk Fuel and Energy Complex and more fully assimilate the Ekibastuz Basin.

Develop the extraction of oil shale in the European part of the country.

Accelerate the development and assimilation of series production of mechanized complexes of equipment for the extraction of coal from thin, dipping seams and sharply dipping seams, increase the production of header combines, loading machines, and other equipment for the coal industry.

Develop and introduce new means of ensuring safe working conditions at enterprises of the coal and [oil] shale industries. Strengthen scientific research, design, and experimental work on the creation of machinery for extracting coal without human labor.

Increase labor productivity in the coal industry by 24–26 percent.

f. Ferrous Metallurgy

Significantly improve the quality, expand the assortment of metal products, and save, in this way, by 1980, 5–6 million m.t. of metal [annually] in the national economy.

Increase by 1.5–2 times the output of efficient types of metal products: cold-rolled sheet steel, coated rolled steel, curved shapes, tempered, rolled low-alloy steel, stainless and transformer steel, and cold-rolled steel sheet. Reduce the consumption of [raw] steel per unit of rolled steel products.

Substantially increase the production of high-strength pipes, above all oil-field pipe with new types of joints, cold-rolled dynamo steel, high-quality steel hardware, iron powders and powders made from alloyed steels and alloys, precision alloys, and also cermets. Organize the production of crude oil and gas pipes with protective coatings.

g. Geological and Prospecting Work

Significantly expand work in order to further increase mineral and raw material resources, primarily in areas with operating mining enterprises and in newly assimilated regions of the country.

Increase the economic efficiency of exploratory and prospecting work and the quality of the preparation of reserves of mineral resources. Ensure priority growth of surveyed reserves of minerals in comparison with the development rates for the extractive branches of industry.

Accelerate the discovery and prospecting of new deposits of crude oil, natural gas, and condensate, primarily in the Middle Ob region, northern Tyumen Oblast, East Siberia, the Yakut ASSR, the Komi ASSR, Archangelsk Oblast, Central Asia, and the Kazakh SSR (the Caspian Depression). Ensure the preparation of additional surveyed reserves of crude oil and gas in regions with deposits under development in the European part of the country. Expand geological prospecting work in the shelf zones of the seas and oceans, most of all for crude oil and natural gas. Strengthen prospecting for deposits of coking and steam coal (especially in the European USSR), rich and easily enriched ores for ferrous and nonferrous metallurgy, precious metals and diamonds, raw materials for nuclear power, and the production of mineral fertilizers.

Raise the level of the provision of equipment in geological prospecting work; create and introduce into production new and highly productive equipment, automated drilling equipment, apparatus, and instruments. Expand the application of progressive geophysical and geochemical methods, use of space, and aerial methods of geological research.

h. Power Machine Building

Ensure the production of the necessary quantity of power units with 500- and 800-MW capacities (which are to become the basic units of electrical power stations operating on organic fuel) and also the output of powerful hydraulic and gas turbines.

Organize the series production of nuclear power stations with thermal-neutron reactors and turbine units for them with unit capacities of up to 1,500 MW.

Accelerate the development of nuclear power machine building on the basis of the full utilization of capacities and the reconstruction of operating enterprises, construction of new plants, and also wide cooperation with other branches of industry in the manufacture of individual units and parts.

Organize the production for electric-power engineering of economical steam and gas facilities with capacities of up to 250 MW, and gas-turbine power facilities with capacities of up to 100 MW for covering peak loads. Increase the production of forced-draft machines, and fully satisfy the requirements of electric power engineering and other branches for these machines.

Develop new designs, create experimental-industrial models, and organize the series production of automated gas-pumping aggregates with remote control in large block and non-baseload versions powered by 6- to 25-MW gas turbines and electric motors. Significantly increase the operating life of the gas-pumping units being developed and increase the time between repairs by two to three times.

i. Heavy Machine Building

For the coal and ore mining industries, assimilate the production of large excavators, dump cars with capacities of up to 170 m.t., and highly productive drilling machinery with boring diameters up to 400 mm.

Organize the production of new types of diesels with progressive technical and economic characteristics and large unit capacity for ships, locomotives, drilling equipment, construction and road building machinery, and heavy dump trucks.

j. The Electrotechnical Industry

Assimilate the production of turbogenerators with 1,000- to 1,200-MW capacity for nuclear and thermal-electric power stations, 640-MW generators for hydroelectric stations, high-voltage equipment for power-transmission lines with voltages up to 1,500 kv DC and up to 1,150 kv AC; highly productive and reliable equipment for the electric drilling of crude oil and gas wells, oil pumping, for gas and crude oil pipelines, and mechanized complexes for extracting coal; main-line freight electric locomotives larger than 10,000 hp.

k. Chemical and Petroleum Machine Building

Organize the production of general-use drilling rigs equipped with special means of transport, highly efficient drill bits, down-hole motors, new types of oil and gas equipment, and highly mechanized machinery for the assimilation and repair of oil and gas wells.

l. The Automobile Industry

Begin the creation of new designs of powerful truck tractors and multiaxle, heightened-mobility vehicles with gas turbines.

Expand the production of [natural] gas-powered automobiles, supplying them mainly to motor pools in large cities.

m. Construction, Road, and Municipal Machine Building

Organize the production of special construction equipment to ensure a faster pace and better quality in the construction of trunk crude oil and gas pipelines.

2. Main Directions of the Development of Natural Science and Engineering

Develop theoretical and experimental research in the fields of nuclear physics, plasma physics, solid-state physics, low-temperature physics, radiophysics and electronics, quantum electronics, mechanics, optics, and astronomy with the goal of accelerating scientific and technical progress—especially the development of nuclear power, improving the existing and development of new methods of energy conversion, the creation and broad introduction of basically new technology and new construction magnetic semiconductor, superconductor, and other materials and technically valuable crystals.

Develop the scientific principles of the rational use and conservation of the soil, the earth's interior, the plant and animal worlds, air, and water.

Expand the study and exploration of the earth's crust and upper mantle with the goal of studying the formation processes and regularities of the location of useful minerals.

Continue the study and exploration of space, expand research on the use of devices in space to study the earth's natural resources, meteorology, navigation, communications, and for other needs of the national economy.

3. Siting of Productive Forces.
Development of the Economies of the Union Republics.

a. General

Provide for the further development of the economic potential of the eastern regions and their increased role in all-union industrial output. Rapidly develop the branches that have, in this regard, the most favorable natural prerequisites (in particular the fuel industry) and energy-intensive production. Provide for the entire increment in this five-year plan's growth in oil and gas extraction and over 90 percent of the growth in coal extraction to come from these regions.

Provide for the development of existing and formation of new territorial-production complexes and industrial centers.

Construct large oil and gas pipeline systems from northwest Siberia and Central Asia to the European USSR and oil pipelines from northwestern Siberia to the petroleum refineries in the eastern regions.

b. The RSFSR

Increase [annual] crude oil production, including gas condensate, to 545–555 million m.t.; gas to 220–255 billion m^3; coal production to 428–438 million m.t.; and electricity generation to 832–851 billion kwh by 1980.

[In the European USSR and the Urals] strengthen the electricity-generation base by constructing and expanding nuclear and thermal-power stations. Increase the capacity of the Leningrad NPS to 4,000 MW and the Kostroma GRES to 3,600 MW. Put new capacity on-line at the Smolensk and Kursk NPS's, the Cheboksary and Nizhne-Kamsk GES's, the Ryazan and Stavropol GRES's and other stations. Intensify the construction of the Perm GRES and begin construction of the Irganay GES.

Continue to develop a large industrial complex for extracting and processing gas based on the Orenburg gas condensate deposit. Construct a gas pipeline [from Orenburg] to the western border of the USSR with assistance from the CMEA nations.

Develop the natural resources of the Timano-Pechora oil and gas province. Increase the [annual] extraction of petroleum there to 25 million m.t. and gas to 22 billion m^3 by 1980.

[In Siberia] accelerate the development of the fuel industry and energy-intensive industries (ferrous and nonferrous metallurgy, chemicals, petrochemicals, and pulp and paper).

Continue to create the largest territorial-production complex—for extracting crude oil and gas. Increase [annual] extraction of crude oil there to 300–310 million m.t., and gas to 115–145 billion m^3 by 1980.

Construct plants for processing oil-associated gas and construct pipelines for transporting crude oil and gas. Develop the electric power-generating base. Increase coal production in the Kuzbass to 161 million m.t.

Develop a large Kansk-Achinsk surface mine and the Berezovo GRES. Ensure the start-up of the Achinsk Petroleum Refinery. Commission the first sections of the Sayano-Shushensk GES. Begin construction of the Boguchan GES. Ensure the start-up of the Ust-Ilimsk GES. Continue construction of the Gusinoozero GRES.

Complete construction of the Zeya GES [in the Far East], expand construction of the Bureya GES, put on-line the first section of the Kolyma GES.

Begin creation of the South Yakutsk Territorial-Production Complex.

c. The Ukrainian SSR

Ensure a higher rate of growth in electrical power engineering.

Ensure the start-up of new capacity at the Chernobyl, Rovno, and Southern Ukrainian NPS's and begin the construction of two new NPS's. Expand construction of the Chigirin and Zuyevka GRES's. Put the first sections of the Dniestr GES on-line.

Increase the [annual] coal extraction to 226–229 million m.t. by 1980. Develop the Donets Basin through its technical reequipment. Reconstruct existing mines and build new ones.

d. The Uzkek SSR

Ensure an increase in the capacity at thermal power stations and build a new GRES at the Angren coal deposit.

e. The Kazakh SSR

Increase [annual] coal extraction to 124–127 million m.t. by 1980. Increase the primary processing of crude oil by 3.8 times.

Ensure growth in the energy base and the start-up of capacity at the Ekibastuz GRES [No. 1]; and begin construction of the Ekibastuz GRES No. 2 and the Shulbin GES.

f. The Georgian SSR

Ensure the further development of electrical power engineering principally by the use of hydroenergy resources; increase [annual] electricity generation by 1.5 times. Complete the construction of the Inguri GES.

g. The Lithuanian SSR

Expand the construction of the [Ignalina] NPS with 1,500-MW reactor units.

h. The Azerbaydzhan SSR

Expand the construction of the Shamkhor GES.

i. The Kirgiz SSR

Expand the construction of the Kurpsay GES.

j. The Tadzhik SSR

Put the Nurek GES on-line at full capacity and begin construction of the Rogun GES on the Vakhsh River.

k. The Armenian SSR

Complete the first section of the Armenian NPS.

l. The Turkmen SSR

Ensure the growth of electrical-power generation by two times and the refining of oil by 1.5 times.

Put new capacity on-line at the Mary GRES, continue the construction of the Chardzhou Petroleum Refinery, ensure the development of the Shatlyk and other new gas deposits. Increase [annual] gas output to 75–80 billion m^3 by 1980.

m. The Estonian SSR

Ensure the priority development of the shale-oil chemical industry. Commission an experimental installation for processing [oil] shale at the Estonian GRES using power-technology principles.

Appendix B Draft Main Directions Related to Energy for the Eleventh FYP (1981–1985)

1. Main Directions of Selected Branches of the National Economy

Improve the use of fuel and energy resources, reduce the demand for crude oil and petroleum products as a boiler fuel, develop nuclear power engineering at a leading rate.

a. Electrical Power Engineering

Increase the generation of electricity in 1985 to 1,550–1,600 billion kwh, including 220–225 billion kwh at nuclear power stations and 230–235 billion kwh at hydroelectric power stations. Provide for incremental growth of electrical power generation in the European USSR mainly at nuclear and hydroelectric power stations.

Put 24–25 thousand MW of new capacity into operation at nuclear power stations. Continue work on the development of breeder reactors and the use of nuclear fuel for the generation of heat.

Carry out the construction of large hydroelectric stations on rivers in Siberia, the Far East, and Central Asia, taking into account the comprehensive use of hydroresources, and also the construction of pumped-storage electric power stations in the European USSR.

Carry out the construction of heat and power stations using coal from the Ekibastuz and Kansk-Achinsk basins and natural gas and oil-associated gas of Western Siberia at accelerated rates. Put the first section of the 1,500-kv DC transmission line from Ekibastuz to the Center and the 1,150-kv AC line from Ekibastuz to the Urals into operation.

Continue work on the further improvement of the Unified Power System of the country and increase the reliability of electricity supply to the economy.

Ensure the further development of the centralized heat supply system by constructing heat and power stations and large regional boiler stations, lowering fuel consumption per unit of output and lowering the cost of electricity and heat.

Raise labor productivity by 18–20 percent.

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b. The Petroleum Industry

Provide for an increase in the production of crude oil (including gas condensate) to 620–645 million m.t. by 1985.

Develop the crude oil extraction industry in the regions of Western Siberia, the Kazakh SSR, and in the northern European USSR at a heightened pace; provide for the accelerated commercial development of new oil fields on the basis of the wide application of industrial construction methods and the use of modular equipment with a high degree of prefabrication.

Expand the application of new methods of working oil-bearing strata and increase, thereby, the extraction of oil. Introduce the progressive method of gas-lift exploitation of wells and highly productive submersible electric pumps.

By 1985 increase the relative share of oil extracted at comprehensively automated fields to 85–90 percent. Lower labor costs per well by 15–18 percent.

Improve the technical and economic indicators of drilling work by accelerating its technical reequipment and by the further improvement of its organization.

c. The Petroleum Refining Industry

Increase the effectiveness of the use of crude oil, ensure further increases in the depth of refining, reduce the loss of oil and oil products.

Assimilate the large-tonnage production of aromatic hydrocarbons, liquid paraffins, ethylene, and petroleum electrode coke. Increase the production of highly effective fuel and lubricant additives.

Increase the quality of petroleum products. Carry out a further unification of the types of lubricating oils, greases, and motor and boiler fuels.

Ensure the planned growth in the volume of production mainly through increases in labor productivity.

d. The Gas Industry

Consider the most important task to be the program for the rapid development of gas extraction. By 1985 increase [annual] gas extraction to 600–640 billion m^3. Create the conditions for further acceleration of the development of the branch.

Introduce at gas fields highly productive, automated modular gas preparation installations.

Increase the capacity for comprehensive processing of oil-associated and natural gases, obtaining thereby ethane, sulfur, and other associated components. Increase the extraction of gas condensate and ensure fuller use of it. Begin the formation of an industrial complex for the extraction and processing of gas and [gas] condensate and the production of sulfur at the Astrakhan Gas Condensate Field.

Carry out the construction of large, trunk gas pipelines with a high degree of automation and operational reliability.

Increase the effectiveness and reliability of operation of the Unified Gas Supply System. Continue to create underground gas storage reservoirs in the major fuel consuming regions.

Increase labor productivity by 33–35 percent.

e. The Coal Industry

Ensure the extraction of 770–800 million m.t. of coal [annually] by 1985.

Develop the extraction of coal at leading rates by the more effective open-pit methods based on the broad introduction of progressive technology and mine transport equipment with large unit capacities. Accelerate the creation of capacity in the Kuznetsk Basin; accelerate the construction of facilities in the Kansk-Achinsk and Ekibastuz fuel and energy complexes, and increase the extraction of coal in these regions.

Carry out the further development of underground coal mining, especially for coking and home fuel needs; the extraction of coal by the hydraulic method; and also the transport of coal by pipeline.

Increase the quality of coal supplied to the economy.

Increase the capabilities of mine construction organizations.

Accelerate the development and series production of highly productive complexes of equipment for coal mining in complex geological conditions and for preparatory operations. Expand the creation and introduction of automated means of coal extraction in mines without the presence of workers in the face area.

Improve labor conditions and the condition of safety equipment.

Achieve growth in coal output and processing mainly by increasing labor productivity.

f. Ferrous Metallurgy

Rapidly develop the production of economical and special types of steel tubes: threaded oil pipe with new types of threaded joints and anticorrosion coatings, high-strength pipe for high pressure boilers and bearings and tubes for nuclear power engineering.

Achieve a fuller use of secondary energy resources.

g. Geological Surveying

Ensure the accelerated development of geological study of the country, increasing the prospected reserves of minerals and raw materials, primarily fuel and energy resources. Carry out measures for the discovery of deposits of oil and gas in the territories of Eastern and Western Siberia, the European USSR, Central Asia, the Kazakh SSR, and also the continental shelf. Expand the raw materials base of operating mining enterprises, especially in regions where territorial-production complexes are being formed. Strengthen the search for and surveying of beds of rich and easily enriched ferrous and nonferrous ores, bauxites, phosphorites, coal, oil shale, and raw materials for nuclear power engineering, and the production of construction materials, mineral fertilizers, and underground water.

Develop progressive types of geophysical and geochemical research on the earth's interior at more rapid rates; in geology widely use the opportunities afforded by high-altitude and space modes of studying earth's natural resources; develop and apply methods of accelerated geological and economic assessments of raw material deposits. Ensure further technical reequipment of geological survey organizations, supplying them with highly effective equipment and transport.

h. Power Machine Building

Ensure a substantial growth in the production of equipment for nuclear, hydro-, and thermal electric power stations, including 1,000- to 1,500-MW reactors for nuclear stations and 500–800 MW power blocks burning low-grade coal for thermal stations. Finish the construction and delivery of the first nuclear reactors for heat supply to large cities. Develop new designs of power blocks with 800 to 1,600-MW, fast-neutron reactors and 500-MW, variable-load blocks. Create an experimental-industrial, steam-gas installation with 250-MW capacity with intracycle gasification of solid fuel.

Increase the production of equipment for using by-product energy resources in metallurgy and other branches of industry. Organize the series production of gas-pumping aggregate units for main gas pipelines with 100-atmosphere pressure.

i. Heavy and Transport Machine Building

Substantially increase the production of new types of large-capacity continuous-mining equipment and mine transport machinery.

Carry out work on creation of systems of machines for comprehensive mechanization of labor of miners in complex geological conditions.

j. The Electrical Equipment Industry

Significantly increase the production of 1,000- to 1,500-MW turbogenerators and complexes of electrical equipment with operating voltages of 1,150 kV AC and 1,500 kV DC, and for oil- and gas-pumping stations.

Organize the production of complex electrical equipment for powerful excavators, rotary [excavating] complexes, and drilling machinery.

k. Chemical and Petroleum Machine Building

Ensure the creation and production of highly productive equipment, including unique and principally new processes in the chemical, petroleum, gas, oil and gas processing, and petrochemical, microbiological, and the pulp and paper industries and in geological prospecting.

Ensure the production of complex drilling equipment capable of being set up anywhere and equipment for cluster drilling, equipment for mechanized operation and repair of wells, automated and modular equipment for outfitting oil and gas fields.

l. The Automotive Industry

Assimilate the production of highly effective, large-capacity dump trucks for surface mines. Increase the fuel efficiency of internal combustion engines and improve their design.

2. Selected Main Directions of Transport and Communications

Expand the sphere of application of new means of transport in the northern regions of the country.

a. Pipeline Transport

Rapidly develop pipeline transport, especially for transport of petroleum products, crude oil, and gas.

Increase the quality of construction of pipelines and ensure their reliable operation. Carry out measures for significantly increasing the productivity of newly built gas pipelines and the automation of compressor stations. Develop and introduce technology for the year-round construction of pipelines in difficult-to-access regions with adverse natural and climatic conditions.

b. Air Transport

Carry out measures for significantly reducing fuel consumption by means of the efficient operation of aircraft, by reducing the loss of fuel, by increasing the economic efficiency of engines, and by improving the weight and aerodynamic characteristics of aircraft and helicopters.

c. Industrial Transport

Accelerate the introduction of continuous and new specialized means of transport, including container, pneumatic-container, hydraulic, and other means, especially in the mining and chemical industries and at the plants in the construction-materials industry.

3. The Development of Science and the Acceleration of Technical Progress

Develop types of transport that are new in principle and also transport power equipment that will substantially reduce fuel and energy expenditure.

Develop the physics of elementary particles and the atomic nucleus, with the goal of furthering the understanding of the structure of matter.

Develop nuclear power engineering and create the principles of thermonuclear power engineering; improve the methods of converting and transmitting energy.

Create chemical-technological processes for producing new substances and materials with given properties; create the scientific principles of a technology for comprehensive use of raw materials and by-products that conserve energy and labor resources and that use closed technological cycles.

Increase the quality, reliability, economic efficiency, and producibility of machines, equipment, and other products of machine building and lower their material and energy intensity.

4. Siting of Industry, Economic and Social Development of the Union Republics

a. General

Carry out large projects for the assimilation of the natural resources [of the eastern regions] and develop the fuel, energy, and raw materials base of Siberia and Kazakhstan. Concentrate the creation of energy-intensive industry here.

Widely develop nuclear energy [in the European USSR and Urals].

b. The RSFSR

Increase [annual] electrical power generation to 950–970 billion kwh by 1985; extraction of crude oil, including gas condensate, to 560–580 million m.t.; and gas to 420–460 billion m^3.

Put new capacity at the Smolensk, Kalinin, and Kursk NPS's on-line.

Put new capacity (in the Volga region) on-line at the Cheboksary and Nizhne-Kamsk GES's, and also at the Balakhovo NPS.

[In the northern Caucasus region] continue work on the use of hydroresources. Put new capacity on line at the Rostov NPS and at the "Atommash" Plant.

[In the Urals] put new capacity on-line at the Perm GRES.

[In Siberia] increase [annual] extraction of crude oil, including gas condensate, to 385–395 million m.t. and gas to 330–370 billion m^3 by 1985.

Increase the extraction of steam and coking coal in the Kuzbass.

Continue the formation of the Kansk-Achinsk Territorial-Production Complex. Put the first sections of the Berezovo Surface Mine No. 1 and the Berezovo GRES No. 1 into operation. Ensure further development of the Sayan Territorial-Production Complex. Largely complete construction of the Sayano-Shushensk GES.

Expand the construction of the Boguchan GES, put the first units of the Kharanor GRES on-line, and complete the construction of the Gusinoozero GRES.

[In the Far East] continue formation of the Southern Yakutsk Territorial-Production Complex, complete the construction of the coal mine, coal preparation plants, and the first section of the Neryungri GRES.

Put the first units of the Bureya GES and Yakutsk GRES No. 2 on-line, finish building the Primorye GRES and the Kolyma GES.

c. The Ukrainian SSR

Increase the [annual] production of electric power to 280–290 billion kwh by 1985, achieve this growth primarily through nuclear power. Expand the construction of and put the first units on-line at the Khmelnitskiy, Zaporozhye, and Crimean NPS's and the Odessa Nuclear Power and Heat Station; ensure increases in the capacities of the Chernobyl, South Ukrainian, and Rovno NPS's; accelerate the construction, reconstruction, and technical reequipment of coal industry enterprises; increase the production of coal.

d. The Uzbek SSR

Increase [annual] electricity generation to 44–45 billion kwh by 1985.

Put new capacity on-line at the Angren GRES No. 2.

e. Kazakh SSR

Increase the extraction of coal to 134 million m.t.

Increase [annual] electricity generation to 90–95 billion kwh by 1985.

At the Pavlodar-Ekibastuz Territorial-Production Complex expand the output of coal, continue to equip large GRES's with 4,000-MW capacity each.

f. Georgian SSR

Increase [annual] electricity generation by 1.2 times.

Finish building the Tskhinvali Hydroelectric Complex, continue the construction of the Khudon GES, and begin construction of the Namakhvan GES.

g. Azerbaydzhan SSR

Develop resources of oil and gas for the stabilization of output.

Put the Shamkhor GES and the Azerbaydzhanian GRES into operation.

Increase [annual] electricity generation to 20 billion kwh by 1985.

h. Lithuanian SSR

Increase [annual] electricity generation by 2.4 times and oil refining by four times.

Ensure the start-up of the first section of the Ignalina NPS, the Vilnyus Heat and Power Station No. 3, and the second section of the Mazheykyay Oil Refinery.

i. The Latvian SSR

Expand the construction of the Daugavpils GES.

j. The Kirgiz SSR

Complete the construction of the Kurpsay GES and add capacity at the Tash-Kurmir GES.

k. The Tadzhik SSR

Expand construction of the Rogun GES and put the Baypazin GES into operation. Increase [annual] electricity generation to 16 billion kwh by 1985.

l. The Turkmen SSR

Increase [annual] electricity generation by 1.8 times.

Appendix C Energy-Related Main Directions and Problems of Science for Selected Institutes

1. Main Directions of the USSR Academy of Sciences (AN SSSR) and Its Scientific Centers, Branches, and Divisions

a. Most Important Problems of the Ural Scientific Center of the AN SSSR

Study connected with the prospective development of the mineral raw materials base of the Urals and comprehensive use of raw materials (including enrichment of materials by structure, formation, and composition of the core and the upper mantle of the Urals; forecasting mineralization; study of the conditions of forecasting mineralization; study of the conditions of formation and regularities of distribution of mineral resources; study of the economic and geological perspectives of expansion of existing and development of new mineral raw materials regions of the Urals).

Development of the physical-chemical bases of new metallurgical technologies, including fundamental researches on theory of metallurgical processes at metallurgical production sites in the Urals (direct production of iron from ore, powder metallurgy, electroslag and arc melting).

Study of the protection of the environment.
(*Vestnik AN SSSR*, 1978, no. 7, p. 9)

b. Main Tasks (Zadachi) of the Karelian Branch of the AN SSSR

Forecasting natural resources on the basis of fundamental research in geology, tectonics, magmatism, metamorphism, and the history of the development of the Precambrian and Quaternary period deposits of Karelia; study of water resources of the republic and development of scientific bases of their use and protection; analysis of the future development and location of productive forces, increasing effectiveness of social production.
(*Vestnik AN SSSR*, 1976, no. 4, pp. 56–57)

c. Main Tasks of the Dagestan Branch of the AN SSSR

Research in the area of physics of semiconductors; study of semiconductors; study of the thermal and physical properties of substances in solid, liquid, and gas state.

Comprehensive research on geological structure and features of geotectonic development of the territory of the republic, conditions of formation and laws of distribution of mineral resources; research in the area of geochronology, seismology, and geothermal conditions.

Development of scientific bases for increasing the productivity of the terrain of the republic and study of the dynamics of hydrobionics of the central part of the Caspian Sea basin, cycles of substances and their migration in biogeocenosis.
(*Vestnik AN SSSR*, 1976, no. 11, p. 24)

d. Main Directions of Development of the National Economy Directly Related to the Work of the Section for Earth Sciences of the AN SSSR

Develop scientific bases for the rational utilization and protection of the soil and the earth's interior. Expand comprehensive research on the world ocean.

Expand the study of the earth's mantle and crust for the purpose of studying the processes of formation and regularities of distribution of mineral resources beds.

Continue study of space and expand the use of space during the study of the natural resources of the earth.
(*Vestnik AN SSSR*, 1976, no. 12, p. 34)

e. Main Directions of Work of the Division of Physical-Technical Problems of Power Engineering of the AN SSSR in the Area of Power Engineering

Rational utilization of natural power resources and various types of energy required by the national economy; improving existing and creating principally new sources and methods of producing, transforming, and transmitting various types of energy, and also methods and means of optimal control of large power systems; research on the interaction of the fuel-energy complex with the environment; development of fundamental problems of thermal physics and electrophysics.
(*Vestnik AN SSSR*, 1975, no. 10, p. 3)

f. Main Tasks of the Komi Branch of the AN SSSR

Study of the problems of formation of mineral resource deposits in the northeastern European part of the country; development of long-term forecasts of comprehensive utilization of natural resources, substantiating principal directions of development of the productive forces of the European northeast; research in the area of chemical processing of organic and inorganic raw materials for their fullest use.
(*Vestnik AN SSSR*, 1977, no. 1, pp. 42–43)

2. Main Directions, Important Problems, and Tasks of Individual Institutes of the Academies of Sciences of the USSR and the Ukrainian SSR

a. Main Scientific Directions for the Chemistry Institutes of the Siberian Division of the AN SSSR (SO AN SSSR)

Physical chemistry: research in the area of catalysis, theory of chemical structure, reaction potential, kinetics, chemistry of solids.

Inorganic chemistry: development of scientific principles of new effective extraction, ion exchange crystallizing, electrolytic and other methods of purifying metals, creation of new inorganic materials with given properties.

Organic chemistry: research in the area of high molecular and natural compounds, petrochemistry.

(*Izvestiya Sibirskogo otdeleniya AN SSSR, seriya khimicheskikh nauk*, 1977, no. 4, p. 3)

b. Main Directions of the Institute of Cybernetics, Academy of Sciences of the Ukrainian SSR

Development of large and super-large machines based on microprocessors and new technology: electronic and ionic.

Development of special devices for gathering and processing information based on small equipment with integrated circuits.

(*Ekonomicheskaya gazeta*, July 1976, no. 30, p. 15)

c. Main Directions of the Institute of Physics of Solids, AN SSSR

Study of atomic, crystal, and electronic structure of solids; study of the effect of defects in crystal structure on the physical properties of solids; study of the mechanism and kinetics of transformations of solids in conditions of high and low temperatures, high pressures, high vacuums, strong magnetic fields, and also streams of radiation; research on the processes of crystallization from liquid and gas phases (development of methods of producing semiconductor crystals, including magnetic semiconductors, oxides, and halides; development of methods of hydrothermal synthesis of crystals, methods of producing high temperature profiled crystals and products from them); creation of new methods of producing highly pure substances, their analysis, and research on their properties; development of new construction materials and technological processes for the needs of contemporary technological processes and equipment.

(*Vestnik AN SSSR*, 1977, no. 2, p. 6)

d. Main Directions of the Institute of Physics of Metals of the Ural Scientific Center, AN SSSR

Theory of solids, physics of strength and plasticity, physics of magnetic phenomena, superconductivity, physics of semiconductors.

(*Vestnik AN SSSR*, 1976, no. 12, p. 17)

e. Main Directions of the Institute of Physics of the Earth imeni Shmidt, AN SSSR

Study of the structure of the earth as a whole and its large parts; study of the processes

of formation of the earth; study of contemporary movements of the earth's crust; research on the properties of the substances of the earth; improvement of seismic services in the country; research on geothermic structure and geoelectricity; comprehensive geological and geophysical study of the crust and the upper mantle of the world ocean; development of geophysical methods of prospecting; improvement of the means of registration of geographic processes, their automation and transfer to machine processing and interpretation of observations.
(*Vestnik AN SSSR*, 1977, no. 12, p. 36)

f. Main Directions of the Institute of Applied Mathematics, AN SSSR

Development of mathematical methods and solutions of pressing tasks connected with the acceleration of scientific and technical progress.
(*Vestnik AN SSSR*, 1976, no. 11, p. 4)

3. Main Directions of Scientific Research Expressed by Individual Scientists

a. A. A. Trofimuk, deputy chairman of the SO AN SSSR, director of the Institute of Geology and Geography of the SO AN SSSR—Tasks of Geology

Study of the earth's crust and upper mantle for research on the processes of formation and laws of distribution of mineral deposits; acceleration of location and prospecting for new oil and gas deposits, especially in the Middle Ob region, north Tyumen Oblast, East Siberia, and the Yakut ASSR; complex regional study of sedimentary basins of the USSR using modern methods; development of direct methods of prospecting for beds of hydrocarbons in the earth's core.
(*Vestnik AN SSSR*, 1976, no. 3, p. 8)

b. N. N. Nekrasov, Academician

Problem of territorial distribution of water resources and diversion of part of the flow of northern and Siberian rivers to Central Asia, Kazakhstan, and the Volga River basin.
(*Vestnik AN SSSR*, 1976, no. 9, p. 59)

4. Main Directions and Problems in Individual Fields of Science and Technology

a. Main Directions for the Development of Computerized Systems

The number of computerized systems for the control of technological processes should more than triple in comparison with the last five-year plan.

Computerized management systems for entire industries (OASU) must be capable of performing very complex tasks of management.
(*Pravda*, February 17, 1976, p. 3)

b. Most Important Problems in Nuclear Energy

Lessening cost and accelerating construction of nuclear electric power stations by means of strengthening the unit power, increasing the coefficient of efficiency, standardization and unification of equipment and elements thereof, and application of cheaper materials without loss of reliability.

Providing high reliability and economical operation of nuclear power stations by means of ensuring high-quality equipment, shortening overloads and repair downtimes, observation by personnel of operational parameters, automation of control of reactors, and equipping active zones with measurement devices.

Uncovering power reserves by means of development of new research in the area of hydrodynamics, thermal physics, and neutron physics; study of the behavior of materials and elements of equipment during forced modes.

Guaranteeing the possibility of work of nuclear electric power stations in variable modes by means of creation of fuel elements capable of withstanding long cyclical loads; study of the reliability of elements of equipment in conditions of variable loads.

Study and development of plans for the development of nuclear power for the long term and strategy for the nearer periods, in particular, in the area of combined heat and power supply and high-temperature technology.
(*Vestnik AN SSSR*, 1978, no. 7, pp. 60–61)

c. Directions of Human Ecology

Study of the urbanized biogeocenosis.

Study of the reverse effect of change of the natural environment on man and society; compilation of ecological and economic characteristics of large regions.

Design of ideal schemes of development of the biogeocenotic cover of a single economic-geographic region.

Design of an ideal scheme of harmonic development of nature, and economics of single geographic systems.

Development of a general scheme of optimal development of economics of a territory; development of accompanying optimization of its biogeocenotic cover.
(*Vestnik AN SSSR*, 1976, no. 12, p. 88)

d. Scientific Problems and Directions in Geology, Geophysics, Geochemistry, and Mining

Geochronology and correlation of geological events and processes; sedimentary processes and sedimentary basins of the geological past; geology of the Precambrian period; global tectonic processes; geological structure, geophysical properties, and geochemical processes of the ocean floor; geology of the continental shelf and landlocked seas of the USSR; geological structure of the territories of the USSR and regularities of the location of minerals; regularities of the location of oil and gas deposits and forecasting of oil and gas resources of the USSR; geochemical processes in the earth, their history and evolution; experimental problems of geology, mineralogy, and petrography; engineering geology; hydrology.
(*Vestnik AN SSSR*, 1976, no. 12, pp. 37–42)

5. Main Directions Established for Other Organizations

a. Main Directions of the Scientific Council on the Problem "National Economic Utilization of Explosions"

Research on development of new methods of construction of large dams by using explosions and research on optimal schemes of using explosions in rocky regions; control of sliding during explosions and movement of blast force through rock; study of the effect of explosions and technical structures on tectonic activity; ensuring seismic safety of explosion work; expansion of production of and creation of new and cheap explosive substances; development of fundamental principles of mechanization of explosions in the construction of canals.
(*Vestnik AN SSSR*, 1976, no. 6, p. 15)

b. Scientific Council on Theoretical and Electrophysical Problems of Electrical Power, AN SSSR—Basic Tasks for Further Research

Development of problems of electromechanical transformation of energy.

Development of powerful controlled transformer semiconductor devices.

Development of the theory and methods of mathematical and physical models of electrophysical and electrical power devices and systems.

Problems of electrodynamics and nonlinear systems and media.

Development of problems of strong magnetic and electrical fields.

Problems of physics of electrical discharge in gases and other dielectrics.

Scientific problems of electrical transmission of super-high voltages and new types of transmissions.

Engineering problems of electrical equipment for research in the area of thermonuclear reactions.
(*Izvestiya AN SSSR, seriya energetika i transport*, 1975, no. 5, pp. 26–28)

Appendix D Scientific Problem Councils

1. Councils of the USSR Academy of Sciences (AN SSSR)

Scientific Council on Complex Problems of Power Engineering, 1975–83*

Section on Systems Research in Power Engineering (1982)

Scientific Council for Interdisciplinary Energy Problems, 1982

Scientific Council on the Chemistry of Mineral Solid Fuels, 1976–80; A. A. Krichko, chairman, 1980

Scientific Council on the Problem of Combating Gas during the Working of Coal Deposits, 1982; A. T. Ayruni, chairman, 1982

Scientific Council on the Complex Problem of Management of Transport Processes, 1983; A. A. Voronov, chairman, 1983

Scientific Council on the Application of Methods of Nuclear Physics in Related Fields, 1976–78

Scientific Council for Questions of Biogeocenology and Environmental Protection, 1976–78

Scientific Council on Chemical Kinetics and Structures, 1976–78

Scientific Council on Chemistry of High Energy, 1977

Scientific Council for Computer Engineering and Control Systems, 1976

Scientific Council on the Complex Problem "Cybernetics," 1959–78; A. I. Berg, chairman, 1975

Scientific Council on Physical-Technical Problems of Development of Useful Minerals, 1976–81; D. M. Bronnikov, chairman, 1981

Scientific Council for Complex Research on the Earth's Crust and Upper Mantle, 1976–78

Scientific Council on Exploitation of Oil Deposits, 1975–78

Scientific Council on the Use of Explosions in the National Economy, 1959–77

Scientific Council on Forecasting; V. A. Kotelnikov, chairman

*Years given are dates of problem councils.

Scientific Council on Fuel Cells, 1977

Scientific Council on Problems of Geology and Geochemistry of Oil and Gas, 1975–78; A. A. Trofimuk, chairman

Scientific Council for Geothermal Studies, 1975–83; I. Dvorov, deputy chairman, 1983

Scientific Council on the Problem "New Processes for Producing and Treating Metallic Materials," 1975–76

Scientific Council for Physical Electronics, Plasma Physics, and Methods of Direct Conversion of Thermal Power to Electric Power, 1976

Scientific Council for the Problem "Physics of Low Temperatures," 1976

Council on the Complex Problem of Plasma Physics, 1975–78

Scientific Council on the Complex Problem "Scientific Fundamentals of Electrophysics and Electrical Energy," 1977; V. I. Popkov, chairman, 1977

Scientific Council on the Complex Problem "Research on the Use of Superconductivity in Power Engineering," 1975

Scientific Council on the Problem "Theoretical Fundamentals of Processes of Combustion," 1977; Ya. B. Zeldovich, chairman, 1977

Scientific Council on Theoretical and Electrophysical Problems of Electrical Power Engineering, 1971–77

Scientific Council on the Engineering Problems of Thermonuclear Fusion and Questions of Plasma Physics, 1981; I. A. Glebov, chairman, 1981

Scientific Council on Thermal Analysis, 1977–78; A. V. Nikolayev, chairman, 1978

Scientific Council on the Complex Problem "Thermal Physics," 1976–78

Scientific Council on Fundamental Problems of Prospective Means of Transportation and Transport Power Engineering, 1976

Scientific Council on the Complex Problem of the Unified Transportation System of the USSR, 1977

Scientific Council for the Problem of Formation of Oil and Gas, 1975

Scientific Council on the Problem of Theoretical Electrical Engineering and Electronics, 1975

Scientific Council on Engineering Geology and Soil Science, 1978

Scientific Council on the Problem "Physics of High Temperatures," 1978; Ye. G. Ponyatovskiy, chairman, 1978

Scientific Council for Comprehensive Study of Problems of the Caspian Sea, 1976

2. Councils of the State Committee for Science and Technology (GKNT)

Coordinating Council on the Problem "Synthetic Fuel," 1981

Scientific Council on the Problem of New Processes in the Coke Chemical Industry, 1975–77

Interdepartmental Scientific Research Council on Complex Problems of Conversion of the Natural Environment and Efficient Use of Natural Resources, 1976–77; N. P. Dubinin, chairman, 1977

Interagency Scientific Council for the Problem "Study of the Earth's Interior and Super Deep Drilling," 1977–78; Ye. A. Kozlovskiy, chairman, 1977

Scientific Council on Problems in New Processes and Methods of Production Work in Mining, 1977

Scientific Council on the Problem "New Welding Processes and Welded Structures," 1976

Scientific Council on Power Engineering and Electrification, 1975–77

Scientific Council on Protection of Metals From Corrosion, 1976

Scientific Council on the Problem of Complex Development of Transportation, 1977

3. Other Councils, Affiliations Unknown

Interdepartmental Scientific Council on Laboratory Research Methods Applicable to Oil and Gas Geology, 1976–77

Scientific Methodological Council of Semiconductor and Insulating Technology, 1977

Scientific Technical Council on the Problem of Enriching and Processing Coal, 1977

Scientific Council on Problems of the Baykal-Amur Railroad, 1976

Scientific Council on the Problem "New Processes in the Coke By-Product Industry," 1975

Appendix E Major Soviet Institutes Engaged in Energy R&D

This appendix provides formatted information on the most important research institutes encountered in our review of Soviet R&D on energy. An attempt has been made to collect and organize identifying information on each institute, including Russian and English names, addresses, and affiliations. In addition, we have compiled a brief description of the activities of each institute, plus names of administrators and researchers. Descriptions of activities and lists of personnel are oriented toward the subject matter of this book and do not presume to be representative of all activities or personnel at these institutes. Finally, a few write-ups also include information on major equipment at the facility or other aspects of the institute.

The Russian word "imeni" found in many institute names means "named for." Thus, the "Institute imeni Paton" and "Paton Institute" are synonymous.

Many pieces of information are followed by a year or range of years in parentheses. In most cases the date shown is the publication date of the periodical or book in which the information was found. In the case of personalities the dates show time of affiliation with an organization rather than time as an official or as a holder of a degree. Where a range is given, the range includes the earliest and latest date of affiliation found and should not be taken as evidence of continuous affiliation throughout the period shown. Other numbers in parentheses refer to items in the lists of references at the end of each chapter of this book.

Letters in parentheses refer to the following publications, which provided much of the identifying information:

A. National Foreign Assessment Center, Central Intelligence Agency, *Directory of Soviet Research Organizations*, March 1978.

B. Battelle Memorial Institute, *Directory of Selected Scientific Institutes in the U.S.S.R.*. Columbus, Ohio: Charles E. Merrill, 1963.

C. *Moskva: kratkaya adresno-spravochnaya kniga* (Moscow: A Short Address Handbook). Moscow: Izd. "Moskovskiy rabochiy," 1977.

Key sources of information are listed at the end of a number of write-ups.

All-Union Electrotechnical Institute imeni V. I. Lenin

Russian name: Vsesoyuznyy elektrotekhnicheskiy institut imeni V. I. Lenina (VEI)
Address: ulitsa Krasnokazarmennaya 12, Moscow (C)

Administrative Affiliation: USSR Ministry of the Electrical Equipment Industry (A)
Activities: VEI was created in 1921 with the responsibility of developing the electrification of the USSR. It is still involved in research and development for the electrotechnical industry in conjunction with the production and distribution of electric power. In recent years it has moved out into MHD and high-energy physics research, including basic and applied work on materials, equipment, and processes. Among the types of equipment involved are MHD generators, electrodes, transformers, power transmission systems, insulation materials, thyristors, switches, electro-optical voltage meters, and electron guns.
Personnel: V. P. Fotin, director (A); V. Kozhukhov, deputy director (A); I. M. Bortnik, deputy director (A); F. I. Kovalev, deputy director (A).

All-Union Scientific Research and Project-Design Institute of Pipeline Container Systems
Russian Name: Vsesoyuznyy nauchno-issledovatelskiy i proyektno-konstruktorskiy institut po truboprovodnym konteynernym sistemam (VNIIPI "Transprogress") (C)
Address: Kutuzovskiy prospekt, 31a, Moscow (C)
Administrative Affiliation: NPO "Soyuztransprogress" (Ministry of Construction of Oil and Gas Industry Enterprises)
Activities: A leading institute on slurry and container pipeline transport of solids. In 1977–78 studied coal slurries of Kansk-Achinsk coal; estimated construction and operating costs for a coal slurry preparation plant; participated in the design of the Kuzbass-Novosibirsk coal slurry pipeline (1978); developed a program of work in slurry transport for Minneftegazstroy.
Personnel: Ye. P. Olofinskiy, deputy director (1979–80) (V-118, -120, -121); V. A. Meliya (1979–80); D. B. Ibragimov (1980); F. A. Karimov (1980); V. V. Sharin (1979).
Other Information: VNIIPI "Transprogress" is probably the headquarters organization of the "Soyuztransprogress" Science-Production Association (NPO).

All-Union Scientific Research Institute of Current Sources (A)
Russian Name: Vsesoyuznyy nauchno-isseldovatelskiy institut istochnikov toka (VNIIT)
Address: Yaroslavskoye shosse, Moscow (A)
Administrative Affiliation: USSR Ministry of Instrument Making, Automation Equipment, and Control Systems (A)
Activities: The work of VNIIT is principally in three technical areas involving direct energy conversion: solar energy conversion, electrochemical energy conversion, and thermoelectric energy conversion. Most of the solar energy work deals with photovoltaics, although some solar thermionics, thermophotovoltaic conversion, and other solar energy uses have been studied. The electrochemical work primarily deals with batteries and fuel cells. A considerable amount of the work in all three of the principal technical areas covered is concerned with the development of sensors and instrumentation based on sensor principles as well as the development of primary power converters with thermal or electrical output.
Personnel: N. S. Lidorenko, director (A) (VII-30); G. F. Muchnik; D. S. Strebkov

(vii-57); V. A. Unishkov (vii-57); M. B. Kagan, M. M. Koltun; T. M. Golovner; A. M. Vasilyev.

All-Union Scientific Research Institute of Drilling Equipment

Russian Name: Vsesoyuznyy nauchno-issledovatelskiy institut burovoy tekhniki (VNIIBT)

Address: Leninskiy prospekt, 6, Moscow (C)

Administrative 1Affiliation: USSR Ministry of the Petroleum Industry (iv-67)

Activities: The Institute develops drilling devices and mining monitors. It is especially known for its work on turbodrills, including research and development of light-alloy and plastic polyamide components. Some research has been done in solid-state physics.

Personnel: A. A. Asan-Nuri, director, doctor of technical sciences (1978) (A) (iv-67); M. T. Gusman, doctor of technical sciences (iv-67); R. A. Ioannesyan, doctor of technical sciences (iv-67).

Key Sources: *Neftyanoye khozyaystvo*, 1978, no. 6, pp. 3–11 and front cover.

Institute of Atomic Energy imeni I. V. Kurchatov (A)

Russian Name: Institut atomnoy energii imeni I. V. Kurchatova (IAE)

Address: ulitsa Kurchatova, 46, Moscow (A)

Administrative Affiliation: USSR State Committee on the Utilization of Atomic Energy (GKAE) (A)

Activities: IAE is the leading Soviet atomic research institute and appears to coordinate work in the area of nuclear power. Between 1943 and 1955 the institute was known as Laboratory No. 2 of the AN SSSR and was formed by I. V. Kurchatov. The first Soviet controlled-fission chain reaction was achieved here by Kurchatov and his colleagues in 1946 using the USSR's first nuclear reactor. Development of the Soviet atomic bomb also was carried out at IAE. The institute has carried Kurchatov's name since his death in 1960. A. P. Aleksandrov, the director since Kurchatov's death, is also the president of the USSR Academy of Sciences.

IAE's main research thrusts include scientific leadership of the VVER and RBMK series power reactor development programs; reactors for ice breakers; controlled thermonuclear fusion (which IAE initiated and which is still heavily centered there); theoretical and experimental nuclear physics; superconductivity and nuclear fuel studies.

IAE's research facilities include several research reactors (MR, IRT-2000, and the VVR-S); fusion installations (Ogra and Tokamak), cryogenic facilities, and the "Fakel" electron accelerator. The IRT reactor has been used to undertake projects such as studies of the effects of radiation on materials and the development of radiation shielding for the atomic icebreaker *Lenin*. The institute has assisted in the design and construction of several Soviet bloc nuclear reactors and atomic power plants. Other research of the institute has been concerned with isotope separation, radiobiology, nuclear chemistry, neutron decay, the Mossbauer effect, and polarization of nuclei.

Personnel: A. P. Aleksandrov, director (A) (III-19, -69); I. K. Kikoin, deputy director (A); V. V. Goncharov, deputy director (A); S. A. Topolin, deputy director (A); A. G.

Zelenkov, deputy director (A); F. V. Kondratyev, deputy director (A); V. A. Legasov, deputy director (A) (VII-170, -171, -172); Ye. P. Velikhov, deputy director (A) (III-80); N. A. Chernoplekov, deputy director (A); V. A. Sidorenko, deputy director (A); V. S. Golubev; V. A. Gurashvili; B. B. Kadomtsev, department head (III-80–81); L. I. Rudakov.

Key Sources: Petrosyants, A. M., et al., *Mirnyy atom v stranakh sotsializma* (The Peaceful Atom in the Socialist Countries), Moscow, "Atomizdat," 1979, p. 134.

"Atomic Energy Institute," *Bolshaya Sovetskaya Entsiklopediya* (Great Soviet Encyclopedia), 1970, vol. 2, p. 404.

Institute of Chemistry and Chemical Technology

Russian Name: Institut khimii i khimicheskoy tekhnologii

Address: Krasnoyarsk

Administrative Affiliation: Siberian Division, USSR Academy of Sciences (SO AN SSSR)

Activities: The institute was created in 1980 around the Department of Chemistry and Chemical Technology of the Institute of Inorganic Chemistry (SO AN SSSR) in Novosibirsk. The main directions of research at the institute include the following: "development of the physical-chemical principles and effective technological processes for comprehensive treatment of the raw materials of the Krasnoyarsk Kray, creation of the scientific principles and processes for the chemical treatment of coals of the Kansk-Achinsk Basin."

Personnel: S. P. Gubin, director (1980–81); A. I. Kholkin, acting director since 1981.

Key Source: *Vestnik Akademii nauk SSSR*, 1980, no. 10, p. 139.

Institute of Fossil Fuels (Also rendered as Institute of Combustible Minerals, or Institute of Mineral Fuels)

Russian Name: Institut goryuchikh iskopayemykh (IGI) (C)

Address: Leninsky prospekt, 29, Moscow (C)

Administrative Affiliation: USSR Ministry of the Coal Industry

Activities: IGI is one of the leading coal conversion research institutes in the USSR and the major coal liquefaction research center.

Studies all aspects of the preparation, properties, and utilization of oil, gas, and coal, including underground gasification of coal (1963) (B). Research includes liquefaction of coal (1980); gasification of high-sulfur coal (1973); hydrocracking of distillates from coal (1973); freezing of hard coals (1976); hydropurification of mixtures of coal and petroleum distillates (1975); and thermal solution methods for processing oil shale (1980).

Personnel:

Liquefaction of Coal: A. A. Krichko, director, doctor of technical sciences (1951–81) (V-32, -69, -79, -80, -83, -90, -93, -100, -101, -102); M. K. Yulin, candidate of technical sciences (1972–81) (V-97, -100, -101, -102); T. A. Titova (1968–78) (V-90, -94, -98); V. V. Zamanov (1977–78); A. A. Galkina (1978); V. P. Davydov (1977–78); D. P. Pchelina (1978); R. A. Konyashina (1968–80); D. L. Muselevich (1972–73); T. M. Bronovets (1968); T. M. Ravikovich (1972–73); B. S. Filippov (1968); D. V. Skvortsov (1972–73); T. S. Nikiforova (1968); L. P. Zamanova (1973–76); V. P.

Rengach (1978); S. G. Gagarin (1975–79); S. V. Makaryev (1977); L. V. Semenov, candidate of economic sciences (1975).

Gasification of Coal: V. S. Altshuler, doctor of technical sciences (1958–76); G. P. Sechenov (deceased) (1958–71); A. A. Krichko, director, doctor of technical sciences (1951–81); I. I. Chernenkov, candidate of technical sciences (1977–78); L. I. Larin (1973); L. D. Lenova (1973); I. P. Krapchin (1977–79); O. M. Korolkova (1979); V. V. Lebedev (1976–79); L. P. Nikanorova (1979); G. S. Shafir (1977); A. A. Gavrilova (1977).

Production of Thermocoal: A. A. Krichko, director, doctor of technical sciences (1951–81); I. P. Krapchin (1977–79); V. I. Kirsanov (1977–79); T. S. Smirnova (1977–79); T. I. Markina (1977–79); D. P. Zverev (91977); L. V. Semenov, candidate of economic sciences (1975); S. G. Gagarin (1975–79); I. I. Slivinskaya (1979); O. K. Miyesserova (1979); N. K. Larina (1979); G. B. Skripchenko (1978–79).

Research on Oil Shale: A. B. Voi-Epshteyn (1951–80); M. B. Shpilberg (1980); T. A. Bregadze (1980); A. A. Krichko, director, doctor of technical sciences (1951–81); M. K. Dyakova (1951–54).

Other Information: In existence since at least 1934. Formerly was under the USSR Academy of Sciences. Has a branch in Karaganda (1969).

Key Sources: *Khimiya tverdogo topliva*, 1977, no. 6, pp. 3–10. *Ugol*, 1978, no. 8, pp. 39–41. *Khimiya tverdogo topliva*, 1978, no. 4, pp. 53–63.

Institute of High Temperatures

Russian Name: Institut vysokikh temperatur (IVT) (IVTAN)

Address: Korovinskoye shosse, Moscow (A)

Administrative Affiliation: USSR Academy of Sciences (A)

Activities: IVT is perhaps the leading non-nuclear energy research institute in the USSR. IVT is directed by A. Ye. Sheyndlin who is currently the head of the Soviet synfuels programs. The institute is also one of the two major Soviet institutes engaged in the development of mathematical modeling for energy planning. The modeling effort is headed by Academician L. A. Melentyev, formerly director of the Siberian Power Engineering Institute (SO AN SSSR) in Irkutsk and A. A. Makarov, also formerly of the Siberian Power Engineering Institute.

Perhaps the most notable work of IVT is its continuing program for the development of design technology for central power stations utilizing magnetohydrodynamic (MHD) energy conversion. After earlier work with the U-02 MHD research channel to study the performance of proposed channel materials, IVT built an MHD loop into an existing power plant in Moscow. Called the U-25, the resulting combined power plant has been used since 1975 to study the function and performance of MHD-cycle prototype components in high-temperature combustion gas flow. While we have not studied the work of IVT as a whole, another important area receiving research emphasis has been the development of cryogenic components for advanced power systems, particularly MHD loops employing a superconducting magnet. Most recently, IVT has built and operated a second MHD loop at the Moscow power plant, called the U-25B, using a superconducting magnet system supplied by the United States.

Other Information: IVT grew out of the Laboratory of High Temperatures at the Moscow Power Engineering Institute (MEI) of the USSR Ministry of Higher and Specialized Secondary Education. The laboratory was renamed the Scientific Research Institute of High Temperatures of MEI (NIIVT MEI) probably in 1962. In 1967 the institute received its current name and was transferred to the USSR Academy of Sciences

Personnel: A. Ye. Sheyndlin, director (A) (V-4, -5, -15, -18); Ye. M. Shelkov, deputy director (A); S. I. Pishchikov, deputy director (A); V. F. Baybuz, deputy director (A); L. A. Melentyev, department head (VIII, numerous references); A. A. Makarov, sector head (VIII, numerous references); V. A. Bityurin; M. A. Styrikovich; A. V. Nedospasov; V. A. Ovcharenko; I. A. Mostinskiy.

Institute of Nuclear Power Engineering

Russian Name: Institut yadernoy energetiki

Address: Sosny Settlement near Minsk (A)

Administrative Affiliation: Academy of Sciences of the Belorussian SSR.

Activities: The institute specializes in the development of dissociating gas-cooled nuclear reactors (N_2O_4) and the use of gamma radiation in the national economy. The institute has an experimental 2,000-kw reactor known as the IRT-2000. The institute is divided into radiochemistry laboratories and an isotope laboratory.

Personnel: V. B. Nestorenko, director (1979–82); A. K. Krasin, director (1978) (A); I. I. Salamatov, deputy director (1978) (A).

Other Information: The institute was founded in 1965 from the Division of Atomic Power Engineering of the Institute of Heat and Mass Exchange of the Belorussian Academy. The institute has a subordinate special design bureau, experimental production facilities, and a graduate studies program.

The institute's staff numbers over 1,700, of which 363 (in 1979) were scientific personnel.

Key Sources: Petrosyants, A. M., *Problemy atomnoy nauki i tekhniki* (Problems of Atomic Science and Technology), Moscow, Izd. "Atomizdat," 1979, pp. 408–9. Borisevich, N. A. (editor), *Akademiya nauk Belorusskoy SSR*, (Academy of Sciences of the Belorussian SSR), Minsk, Izd. "Nauka i tekhnika," 1979, pp. 73–74.

Scientific Research and Project-Design Institute of Solid Fuel Preparation

Russian Name: Nauchno-issledovatekskiy i proyektno-konstruktorskiy institut obogashcheniya tverdikh goryuchikh iskopayemykh (IOTT) (C)

Address: VUGI, Lyubertsy 4, Moscow Oblast (C)

Administrative Affiliation: Probably the USSR Ministry of the Coal Industry

Activities: IOTT is the leading institute for coal preparation and coal briquetting in the USSR. Activities cover the entire range of coal preparation technology. IOTT assists in the introduction of new technology at preparation plants. Between 1964 and 1975 IOTT developed countercurrent gravitation washing equipment. See text of chapter 5 for details on IOTT developments in recent years.

Personnel: A. R. Molyavko, director (1977); M. A. Borts, doctor of technical sciences (1976–78); V. V. Belovolov, candidate of technical sciences (1977); I. Kh. Deberdeyev, candidate of technical sciences (1976); Ye. G. Treskov, candidate of technical sciences (1978); E. V. Miller, candidate of technical sciences (1976); A. V. Shlau,

including the development of solar power installations for use in remote areas.
Personnel: S. A. Azimov, director (A); G. Ya. Umarov, deputy director (A).

Scientific Research and Design Institute of Energy Technology

Russian Name: Nauchno-issledovatelskiy i konstruktorskiy institut energotekhniki (NIKIET)

Address: Moscow (probable)

Administrative Affiliation: USSR State Committee on the Utilization of Atomic Energy (GKAE) (Probable)

Activities: NIKIET appears to have been formed around a group of scientists and engineers who organized a separate subdivision of the Institute of Atomic Energy imeni Kurchatov in 1952. NIKIET became an independent institute at some unknown subsequent, but apparently recent, date. The first director probably was N. A. Dollezhal, who is now said to be a chair head at the Moscow Higher Technical School imeni Bauman. The original group was tasked with solution of the engineering problems connected with reactor construction under a general atomic research program headed by I. V. Kurchatov. NIKIET has been referred to as the "chief designer" of many Soviet reactor systems.

The main areas of research of NIKIET have included physics of reactors, thermal physics, materials studies, corrosion and hydrodynamics, reactor testing, measurement, and reliability. NIKIET also worked with FEI on the development of early water-graphite reactors installed at the Obninsk NPS (design work conducted 1954 to 1957), the Siberian NPS (installed in 1958), and the Beloyarskiy NPS. NIKIET is credited with design of the RBMK-1000 and RBMK-1500 water-graphite power reactors under the scientific leadership of IAE. NIKIET also appears to have designed the RBMK-2400, which is still on the drawing board. Another recent development is the design of the VK-500 (500 MW) boiling-water cogeneration reactor.

Key Personnel: N. A. Dollezhal, director (probable) (III-20, -48, -69); I. Ya. Yemelyanov, deputy director (III-20); A. P. Sirotkin (1980); V. V. Rylin (1980); P. A. Gavrilov (1980); V. G. Aden (1980).

Key Source: Morokhov, I. D., "25th Anniversary of the Scientific Research and Design Institute of Energy Technology," *Atomnaya energiya*, 1978, vol. 44, no. 3, pp. 273–77.

Scientific Research Institute of Atomic Reactors imeni V. I. Lenin

Russian Name: Nauchno-issledovatelskiy institut atomnykh reaktorov imeni V. I. Lenina (NIIAR)

Address: Dimitrovgrad (A)

Administrative Affiliation: USSR State Committee on the Utilization of Atomic Energy (GKAE) (A)

Activities: NIIAR is one of the major Soviet centers for nuclear power research. The institute conducts tests of equipment being developed for nuclear power stations on its VK-50 fission reactor and its BOR-60 breeder reactor. NIIAR has a large facility for study of materials for use in reactors. Study of new fuels and zirconium alloys for VVER and RBMK reactors are two of this facility's major R&D thrusts. NIIAR also is involved in the development of small fission reactors for nuclear heat supply stations.

Personnel: V. A. Tsikanov, director (A); N. V. Krasnoyarov, deputy director (A).

Other Information: The institute has been in operation since at least 1961.
Key Source: *Atomnaya energiya*, 1980, vol. 48, no. 4, pp. 211–15.

Scientific Research Institute of Electrophysical Apparatus imeni D. V. Yefremov (A)
Russian Name: Nauchno-issledovatelskiy institut elektrofizicheskoy apparatury imeni D. V. Yefremova (NIIEFA)
Address: ulitsa Kantemirovskaya, 8, Leningrad (A)
Administrative Affiliation: USSR State Committee on the Utilization of Atomic Energy (GKAE) (A)
Activities: Produces accelerators, cyclotrons, and fusion research equipment, but does not participate directly in energy R&D.
Personnel: V. A. Glukhikh, director (1978–81) (A) (III-83); I. F. Malyshev, deputy director (A); M. N. Gushin, deputy director (A); O. A. Gusev, deputy director (A).

Siberian Power Engineering Institute
Russian Name: Sibirskiy energeticheskiy institut (SEI)
Address: ulitsa Lermontov 130, Irkutsk (A)
Administrative Affiliation: Siberian Division, USSR Academy of Sciences (SO AN SSSR)
Activities: SEI is the leading energy modeling institute in the USSR. It has been described as "the base organization of the permanent Energy Commission of USSR Gosplan, the GKNT, and the USSR Academy of Sciences." SEI has played a major role in the creation of the Unified Electrical Power System of the USSR and in the development of the centralized heat supply system. The first mathematical model used by Gosplan for energy development planning was developed by SEI. The model was first used by Gosplan in 1962. Special interest has been given to the development of Siberian fuel and energy resources. In 1975 SEI began joint research with the International Institute of Applied Systems Analysis in Austria. SEI's work in long-range energy forecasting is described in chapter 8.
Other Information: SEI was created in 1960 as the Energetics Institute of the SO AN SSSR. The first director was L. A. Melentyev, who served in that position until 1973, when he moved to the Institute of High Temperatures (IVT) in Moscow. A. A. Makarov also left SEI for IVT at some unknown date in the late 1970s or early 1980s.
Personnel: Yu. N. Rudenko, director since 1973; L. S. Belyayev; Yu. M. Gorskiy; N. I. Voropay; Yu. D. Kononov; A. Vigdorchik.
Key Source: V. L. Makarov (editor), *Akademiya nauk SSSR, Sibirskoye otdeleniye, Khronika, 1957–1982*, (Academy of Science of the USSR, Siberian Division, A Chronicle: 1957–1982), Novosibirsk, Izd. "Nauka," 1982, pp. 42, 63, 182, 270, 297.

State Scientific Research and Project Insititute of the Nitrogen Industry and Products of Organic Synthesis (A)
Russian Name: Gosudarstvennyy nauchno-issledovatelskiy i proyektnyy institut azotnoy promyshlennosti i produktov organicheskogo sinteza (GIAP)
Address: Chkalova ulitsa 50, Moscow (A)
Administrative Affiliation: USSR Ministry for the Production of Mineral Fertilizers
Activities: Involved in gasification of coal to produce synthesis gas as input to produc-

tion of motor fuels (1979). GIAP is a leading institute of the ministry in the field of coal gasification.

Personnel: N. D. Zaichko, director (A); M. S. Furman, deputy director (A); V. M. Olevskiy, deputy director (A); A. M. Alekseyev, deputy director (A); L. M. Shestakov, deputy director (A); L. Z. Novikov (1957).

Other Information: Some work on gasification of coal in the past.

State Scientific Research Power Engineering Institute imeni G. M. Krzhizhanovskiy

Russian Name: Gosudarstvennyy nauchno-issledovatelskiy energeticheskiy institut imeni G. M. Krzhizhanovskogo (ENIN)

Address: Leninskiy prospekt, 19, Moscow (C)

Administrative Affiliation: USSR Ministry of Power and Electrification (A) since 1961; before 1961, USSR Academy of Sciences.

Activities: ENIN is a specialized research institute that focuses on the scientific study of problems associated with power engineering, including electrical engineering, heat exchange, determination of the characteristics and usability of fuels, and the utilization of new energy sources. Recent activities include processes for enrichment of Kansk-Achinsk brown coals; container pipeline R&D; development of solid heat-transfer agent process and equipment for high-speed pyrolysis of oil shale; combustion of low-calorie and waste industrial fuel gases; and analysis of large fuel-and-power complexes.

Personnel: Yu. N. Vershinin, director (1983); I. I. Aladyev, deputy director (A).

Coal Enrichment Processes: Z. F. Chukhanov, corresponding member of AN SSSR (1961–80); V. V. Kalyuzhnyy (1976–78); V. I. Panov (1976–79); A. M. Nikolayev (1976); V. A. Karasev (1976); F. Ye. Keneman (1976); Z. A. Sokolov (1976); Ye. I. Kazakov (1978).

Shale Research: I. S. Galynker, doctor of technical sciences (1945–75); B. I. Tyagunov,* engineer (1963–78); V. I. Chikul (1963–76); B. M. Dolgopolov (1963–76); K. A. Iorudas (1976); A. S. Smirnov (1976).

Container Pipeline Research: Z. F. Chukhanov, corresponding member of AN SSSR (1961–80); Z. Z. Chukhanov (1979); D. M. Apter (1980); S. A. Tsuprov (1979–80); V. I. Panov (1976–79); A. M. Nikolayev (1976–79); I. V. Lyashenko (1979).

Underground Gasification of Coal: Z. F. Chukhanov, corresponding member of AN SSSR (1961–80) (VII-115).

Other Research: V. I. Baryshev (Belorussian Branch) (1976)

Other Information: ENIN was founded in 1930. The institute was directed by G. M. Krzhizhanovskiy, a pioneer of the Soviet electrification program, for over thirty years. ENIN was also directed by D. G. Zhimerin, who is a former first deputy chairman of the GKNT. The institute's work is focused on development of long-range problems of power engineering, improvement of management of the electrical power industry, and study of the most promising methods of producing, converting, transmitting, and storing energy. ENIN has a branch in Minsk. ENIN has cooperated with the Eastern Coal-Chemical Institute in the development of a thermal-contact coking process for Kansk-Achinsk lignite (1976).

*Head of ENIN's shales laboratory, in charge of development and introduction of solid heat-transfer agent unit (UTT) for oil shale pyrolysis (1978).

Appendix F Glossary

AC. alternating current
AN SSSR. Academy of Sciences of the USSR
AN UKrSSR. Academy of Sciences of the Ukrainian SSR
ASSR. Autonomous Soviet Socialist Republic
atm. atmosphere
BTU. British Thermal Unit
BWR. boiling-water reactor
C. Centigrade
CC. Central Committee
CIA. Central Intelligence Agency
cm. centimeter
CMEA. Council for Mutual Economic Aid (COMECON) (CEMA)
CPSU. Communist Party of the Soviet Union
DC. direct current
EHV. extrahigh voltage
ENIN. State Scientific Research Power Engineering Institute imeni Krzhizhanovskiy
F. Fahrenheit
FEI. Physical-Energetics Institute
fnu. first name unknown
FYP. five-year plan
g. gram
GAES. pumped-storage electric-power station
Gcal. gigacalorie
GES. hydroelectric power station
GKAE. State Committee for the Utilization of Atomic Energy
GKNT. State Committee for Science and Technology
GNP. gross national product
GOELRO. State Plan for the Electrification of Russia
Gosplan. State Planning Committee
Gosstroy. State Construction Committee
GRES. state regional electric power station
GW. gigawatt
hp. horsepower

hr. hour
HVPTL. high-voltage power transmission line
IAE. Institute of Atomic Energy imeni Kurchatov
IGI. Institute of Fossil Fuels
IKTP. Institute of Comprehensive Transport Problems
imeni. named for
I-O. input-output
IVT. Institute of High Temperatures
K. Kelvin
KATEK. Kansk-Achinsk Fuel and Energy Complex
KB. design bureau
kcal. kilocalorie
kg. kilogram
KGB. State Security Committee
kgf. kilogram-force
km. kilometer
Kray. A major civil subdivision of a union republic
kv. kilovolt
kw. kilowatt
kwh. kilowatt-hour
lb. pound
m. meter
MEI. Moscow Power Engineering Institute
MHD. magnetohydrodynamics
Minchermet. Ministry of Ferrous Metallurgy
Minelektrotekhprom. Ministry of the Electrical Equipment Industry
Minenergo. Ministry of Power and Electrification
Mingazprom. Ministry of the Gas Industry
Minkhimmash. Ministry of Chemical and Petroleum Machine Building
Minneftegazstroy. Ministry of Construction of Oil and Gas Industry Enterprises
Minnefteprom. Ministry of the Oil Industry
Minugleprom. Ministry of the Coal Industry
Minvodkhoz. Ministry of Land Reclamation and Water Management
MJ. megajoules
mm. millimeter
Mosenergo. Moscow Regional Power Administration
MPa. megapascals
m.t. metric ton
MVSSO. Ministry of Higher and Specialized Secondary Education
MW. megawatt
MW(e). megawatt (electric output)
NGDU. oil and gas extraction administration
NII. scientific research institute
NIIAR. Scientific Research Institute of Atomic Reactors
NIPI. scientific research and project institute
NPO. science-production association

NPS. nuclear power station
Oblast. A major civil subdivision of a union republic
OKB. test design bureau
PO. production association
P.S. underground coal gasification station
PWR. pressurized-water reactor
R. rubles
Rayon. A minor civil subdivision subordinate to an oblast, kray, or autonomous republic
RBMK. high-power, channel reactor
R&D. research and development
rpm. revolutions per minute
RSFSR. Russian Soviet Federated Socialist Republic
sec. second
SEI. Siberian Power Engineering Institute
SES. solar electric power station
s.f. standard fuel
SKB. special design bureau
SO AN SSSR. Siberian Division of the USSR Academy of Sciences
SOPS. Council for the Study of Productive Forces of the USSR Gosplan
SPTL. superconducting power transmission line
SSR. Soviet Socialist Republic
SSSR. Union of Soviet Socialist Republics (USSR)
S&T. science and technology
TASS. Telegraph Agency of the Soviet Union
TETs. heat and power station
TsAGI. Central Aerodynamics and Hydrodynamics Institute imeni Zhukovskiy
TsNIIChermet. Central Scientific Research Institute of Ferrous Metallurgy imeni Bardin
UGC. underground gasification of coal
UHV. ultrahigh voltage
UHVPTL. ultrahigh voltage power transmission line
UPS. unified power system
U.S. United States
USSR. Union of Soviet Socialist Republics
VNII. All-Union Scientific Research Institute
VNIIBT. All-Union Scientific Research Institute of Drilling Equipment
VNIIKTEP. All-Union Scientific Research Institute for Comprehensive Fuel and Energy Problems, attached to USSR Gosplan
VNIIST. All-Union Scientific Research Institute of Main Pipeline Construction
VNIIT. All-Union Scientific Research Institute of Current Sources
VNIPI. All-Union Research and Project Institute
VNITI. All-Union Scientific Research Pipeline Institute
VVER. water-water power reactor

List of References

1 Introduction

1. Kelly, W. J., "Effects of the Soviet Price Reform of 1967 on Energy Consumption," *Soviet Studies* 30, no. 3 (July 1978): 394–402, esp. 397–99.
2. USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR v 1979g.* (The National Economy of the USSR in 1979) (Moscow: Izd. "Statistika," 1980), p. 170.
3. USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR v 1983g.* (The National Economy of the USSR in 1983) (Moscow: Izd. "Finansy i statistika," 1984), p. 152.
4. "Labor Strides of the Five-Year Plan," *Izvestiya* (January 29, 1984), p. 2.
5. "Let's Successfully Finish the Five-Year Plan," *Pravda* (January 26, 1985), p. 2.
6. "Soviet Union Names a New Oil Minister," *Wall Street Journal* (February 13, 1985), p. 34.
7. *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1984, no. W1280, p. A11.
8. Troitskiy, A., "New Frontiers of Soviet Power Engineering," *Planovoye khozyaystvo*, no. 12 (1976): 20–28.
9. "The Institute for Comprehensive Fuel-Energy Problems," *Planovoye khozyaystvo*, no. 2 (1975): 148–49.
10. Makarov, A. A., "Systems Research on the Long-term Structure of the Fuel-Energy Complex of the USSR," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 3 (1980): 21–30, esp. 30.

2 R&D in the Energy Sector

1. Fedorenko, N. P., ed., *Programno-tselevoy metod v planirovanii* (The Program-Target Method in Planning) (Moscow: Izd. "Nauka," 1982), p. 42.
2. U.S. Central Intelligence Agency, "Energy Decision Making in the Soviet Union, A Reference Aid," CR 82-12736 (August 1982).
3. Ivakhnov, A., "Science to Production," *Izvestiya* (December 6, 1983), p. 2.
4. Kelly, W. J., Shaffer, H. L., and Millett, S. M., "Soviet Perceptions of Energy Problems and Planning: A Quantitative Approach," paper presented at the Seminar on Soviet Perceptions of the World Order, Battelle's Columbus Laboratories,

Columbus, Ohio, November 12, 1980, pp. 12, 22, and 24.

5 *BBC Summary of World Broadcasts*, part 2: Eastern Europe (Weekly Economic Report), 1983, no. W1232, p. A1.

6 Statement by A. K. Antonov to a U.S. businessman in 1983. Reported to the authors in a personal communication.

7 NFAC, "Energy Decision Making in the Soviet Union: A Reference Aid," CR 80-10623 (August 1980).

8 Tsapkin, N. V., Gichkin, V. N., and Belik, Yu. A., eds., *Planirovaniye ekonomicheskogo i sotsialnogo razvitiya SSSR* (Planning the Economic and Social Development of the USSR) (Moscow: Izd. "Mysl," 1983), pp. 50–53 (planning methods), 66–69 (Gosplan), 73–75 (long-range planning), 83–86 (programs), 95–96 (R&D plans), 99–100 (S&T programs), and 238 (material balances).

9 "The Institute of Comprehensive Fuel and Energy Problems," *Planovoye khozyaystvo*, no. 2 (1975): 148–49.

10 Ring, M. P., *Khozraschetnaya sistema sozdaniya i vnedreniya novoy tekhniki* (The Khozraschet System of Creation and Introduction of New Technology) (Moscow: Izd. "Nauka," 1982), pp. 213 and 215.

11 Mymrikov, N. S., and Mymrikova, L. S., "Scientific and Technical Progress and the Planning System," *Izvestiya Akademii nauk SSSR, seriya ekonomicheskaya*, no. 5 (1983): 25–35, esp. 32–33.

12 Zaleski, E., Kozlowski, J. P., Wienert, H., Davies, R. W., Berry, M. J., and Amann, R., *Science Policy in the USSR* (Paris: OECD, 1969), p. 58.

13 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1238, p. A5.

14 Makarov, V. L., ed., *Akademiya nauk SSSR, Sibirskoye otdeleniye, Khronika 1957–1982 gg.* (USSR Academy of Sciences, The Siberian Division, Chronicle 1957–1982) (Novosibirsk: Izd. "Nauka," 1982), p. 270.

15 "In the Division of Physical-Technical Problems of Power Engineering," *Vestnik Akademii nauk SSSR*, no. 7 (1977): 81–87, esp. 81–84.

16 "Nuclear Energy, Man, and the Environment" (round table discussion), *Science in the USSR*, no. 4, (1982): 4–7 and 23–26, esp. 5.

17 USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR v 1982 g.* (National Economy of the USSR in 1982) (Moscow: Izd. "Finansy i statistika," 1983), pp. 88, 110–11.

18 Gutyrya, V. S., ed., *Academy of Sciences of the Ukrainian SSSR, A Brief Historical Survey* (in English) (Kiev: Izd. "Naukova dumka," 1980), p. 9.

19 Mikulinskiy, S. R., Kugel, S. A., Maslennikov, V. K., Mirskiy, S. I., and Belishch, P. B., "Training and Employment of Scientific and Engineering-Technical Personnel in the U.S.S.R.," prepared for the USSR Side of the Joint U.S.-USSR Working Group on "Research and Development Manpower," Moscow, February 1976, p. 131.

20 USSR Central Statistical Administration, *Narodnoye khozvaystvo SSSR v 1974 g.* (National Economy of the USSR in 1974) (Moscow: Izd. "Statistika," 1975), pp. 143, 146.

21 Zaynullin, A. I., "Analysis of the Duration of Conducting Scientific-Research Work," *Neftyanaya promyshlennost, seriya ekonomika neftyannoy promysh-*

lennosti, no. 6 (1981): 31–32.

22 Volodko, L., "Scientific Research in Higher Education," *Kommunist Belorussii*, no. 2 (1974): 62–69. [Translated as JPRS 62,034, May 20, 1974, pp. 3–13, esp. 4.]

23 National Science Foundation, "National Patterns of R&D Resources: Funds and Manpower in the United States, 1953–1977," NSF 77–310, 1977, p. vi.

24 Marchuk, G. I., "Scientific and Technical Progress and the Effectiveness of Production," *Pravda* (December 9, 1983), pp. 2–3.

25 Mamedov, D. I., Portnov, A. P., and Aliyev, A. B., "Certain Questions of the Formation and Development of the Academy's Science-Production Associations," *Narodnoye khozyaystvo Azerbaydzhana*, no. 4 (1983): 48–51.

26 Skoblikov, Ye. A., "The Scientific and Technical Revolution and the Development of Production Systems," *Izvestiya Akademii nauk, seriya ekonomicheskaya*, no. 3 (1983): 40–52. [Translated as JPRS 84,497, October 7, 1983, pp. 13–31, esp. 26.]

27 Amann, R., and Cooper, J., eds., *Industrial Innovation in the Soviet Union* (New Haven and London: Yale University Press, 1982), pp. 10, 305, 457, 463.

28 Bashin, M. L., *Effektivnost fundamentalnykh issledovaniy* (Effectiveness of Basic Research) (Moscow: Izd. "Mysl," 1974), p. 90.

29 Gusakov, M., "Organization of the Plant Sector of Science," *Voprosy ekonomiki*, no. 3 (1983): 89–95.

30 Berliner, J. S., "Planning and Management," in Bergson, A., and Levine, H. S., eds., *The Soviet Economy: Toward the Year 2000* (London: Allen & Unwin, 1983), pp. 350–90, esp. 362, 366, 375, 378.

31 Berliner, J., "The Soviet Economy: Prospects for Reform," paper presented at the Mershon Center Seminar on Eastern Europe, The Ohio State University, Columbus, November 16, 1983, p. 5.

32 Kvasha, Ya., "Concentration of Production and Small-scale Industry," *Voprosy ekonomiki*, no. 5 (1967): Cited in reference (30) to this chapter.

33 Karagedov, R. G., "On the Organizational Structure of the Management of Industry," *Ekonomika i organizatsiya promyshlennogo proizvodstva* (EKO), no. 8 (1983): 50–69, esp. 57.

34 Onipko, N., "The Sectoral Headquarters: Extent of Responsibility," *Sotsialisticheskaya industriya* (February 13, 1983), p. 2. [Translated as JPRS 83,481, May 17, 1983, pp. 40–42.]

35 Schroeder, G. E., "Soviet Economic 'Reform' Decrees: More Steps on the Treadmill," in the JEC compendium, *Soviet Economy in the 1980's: Problems and Prospects* (Washington, D.C.: U.S. Government Printing Office, December 31, 1982), part 1, pp. 65–88, esp. 66 (quote), 67–68 (main features of 1979 decree), 73 (energy prices), 81 (organizational changes), and 83 (new success indicators).

36 Nolting, L., "The 1968 Reform of Scientific Research, Development, and Innovation in the U.S.S.R.," Foreign Economic Report No. 11, U.S. Department of Commerce, September 1976, pp. 11 and 14.

37 Decree of the Central Committee of the CPSU and the USSR Council of Ministers, "On the Improvement of Planning and Strengthening of the Influence of the Economic Mechanism on Increasing the Effectiveness of Production and the

Quality of Work," *Sobraniye postanovleniy pravitelstva SSSR*, no. 18 (1979): 390–429, esp. 390–91 (basic plan documents), 394–97 (success indicators).

38 Ambrosius, V. V., "On the Experience of the Experimental Application of New Methods of Financing and Stimulating the Introduction of New Technology," *Izvestiya Akademii nauk SSSR, seriya ekonomicheskaya*, no. 2 (1980): 23–29, esp. 25, 28.

39 Belyanov, V. A., Kamayev, V. D., and Chaplygin, Yu. P., eds., *Nauchno-tekhnicheskiy progress i ekonomika* (Scientific and Technical Progress and Economics) (Moscow: "Profizdat," 1983), pp. 21 and 22.

40 Gosplan SSSR, *Metodicheskiye ukazaniya k razrabotke gosudarstvennykh planov ekonomicheskogo i sotsialnogo razvitiya SSSR*, (Methodological Instructions for the Development of State Plans of Economic and Social Development of the USSR) (Moscow: Izd. "Ekonomika," 1980), pp. 9–10, 10–33 (R&D plan chapter titles).

41 Cocks, P., "Administrative Reform and Soviet Politics," in the JEC compendium, *Soviet Economy in the 1980's*, part 1, pp. 46–64, esp. 46, 50–51 (programs), and 52–55 (party). See reference 35.

42 Kamerling, D. S., "The Role of Territorial Production Complexes in Soviet Economic Policy," in the JEC compendium, *Soviet Economy in the 1980's*, part 1, pp. 242–66, esp. 260–63. See reference 35.

43 Ryabov, Ya., "Administration of Scientific and Technical Progress and the Increase in the Effectiveness of Production," *Planovoye khozyaystvo*, no. 10 (1982): 3–17. [Translated as JPRS 82,674, January 19, 1983, pp. 1–8, esp. 7–8.]

44 Marchuk, G. I., "Comprehensive-Target Programs," *Ekonomicheskaya gazeta*, no. 1 (1983): 2.

45 "Kansk-Achinsk Fuel and Energy Complex (KATEK)," *Ekonomicheskaya gazeta*, no. 2 (1983): 2.

46 "New Types of Transport," *Ekonomicheskaya gazeta*, no. 16 (1983): 2.

47 "Potential of the Petroleum Strata," *Ekonomicheskaya gazeta*, no. 8 (1983): 2.

48 "Unified Electrical Power System of the USSR," *Ekonomicheskaya gazeta*, no. 29 (1983): 2.

49 "Development of Thermal Power Engineering," *Ekonomicheskaya gazeta*, no. 46 (1983): 2.

50 "Renewable Sources of Energy," *Ekonomicheskaya gazeta*, no. 23 (1983): 2.

51 "The Underground Secrets of Nature," *Ekonomicheskaya gazeta*, no. 5 (1983): 2.

52 "New Mining Equipment," *Ekonomicheskaya gazeta*, no. 36 (1983): 2.

53 "Program of Energy Conservation," *Ekonomicheskaya gazeta*, no. 26 (1983): 2.

54 "Deep Processing of Petroleum," *Ekonomicheskaya gazeta*, no. 48 (1983): 2.

55 "Development of Hydro-Power Engineering," *Ekonomicheskaya gazeta*, no. 49 (1983): 2.

56 Campbell, R. W., *The Soviet-Type Economies* (Boston: Houghton Mifflin, 1974), 3rd ed., p. 29.

57 Gvishiani, D., and Milner, B. "Organizational Reserves of Management," *Voprosy ekonomiki*, no. 11 (1983): 3–12, esp. 8.

58 Stewart, P., and Blough, R., "Political Obstacles to Soviet Economic Reform," paper presented at the Mershon Center Seminar on the Soviet Union and East-

ern Europe, The Ohio State University, Columbus, Ohio, January 12, 1984.

59 Karlik, Ye. M., ed., *Ekonomika mashinostroyeniya* (The Economics of Machine Building) (Leningrad: Izd. "Mashinostroyeniye," Leningrad Division, 1977), pp. 418, 428.

60 Schroeder, G. E., "The Soviet Economy on a Treadmill of 'Reforms,'" in the JEC compendium, *Soviet Economy in a Time of Change,* (Washington, D.C.: U.S. Government Printing Office, October 10, 1979), vol. 1, pp. 312–40.

61 Adam, J., "The Present Soviet Incentive System," *Soviet Studies* 32, no. 3 (1980): 349–65.

62 GKNT decree on formation and use of economic incentive funds in scientific-research, design, project-design, and technological organizations, approved April 10, 1982, *Byulleten normativnykh aktov ministerstv i vedomstv SSSR,* no. 3 (1981): 5–17.

63 Babak, V., Logachev, V., and Novikov, V., "Improving the Management of Branch NIIs and KBs," *Planovoye khozyaystvo,* no. 12 (1982): 46–52, esp. 46, 47.

64 Gatovskiy, L., "Economic Stimuli of Scientific and Technical Progress," *Voprosy ekonomiki,* no. 2 (1981): 64–75, esp. 72.

65 Artemov, Yu., "Material Stimuli in the Economic Mechanism," *Voprosy ekonomiki,* no. 11 (1980): 61–68, esp. 67.

66 Rzheshevskiy, V., "Funds of Encouragement in the Economic Mechanism," *Voprosy ekonomiki,* no. 8 (1980): 40–48, esp. 43.

67 Lipchanskaya, L., and Belokon, A., "Khozraschet in Science-Production Associations," *Voprosy ekonomiki,* no. 5 (1982): 63–70, esp. 69.

68 Ryzhkov, N., "Quality of Machines and Material Resources," *Planovoye khozyaystvo,* no. 9 (1981): 13.

69 Berliner, J. S., *The Innovation Decision in Soviet Industry* (Cambridge, Mass.: MIT Press, 1976).

70 Popov, G., "The Expected Effect," *Sovetskaya Rossiya* (May 27, 1983), p. 2. [Translated as JPRS 84,497, October 7, 1983, pp. 56–60, esp. 59.]

71 Busyatskaya, L., "The Economic Experiment in Mintyazhmash," *Planovoye khozyaystvo,* no. 10 (1983): 54–58, esp. 56.

3 Nuclear Electrification

1 Nekrasov, A. M., and Pervukhin, M. G., eds., *Energetika SSSR v 1976–1980 godakh* (Power Engineering in the USSR in 1976–1980) (Moscow: Izd. "Energiya," 1977), pp. 11, 61, and 62.

2 "Results of the Development of Electrical Power Engineering in 1980 and Tasks for 1981," *Elektricheskiye stantsii,* no. 1 (1981): 2.

3 "What Can the Collective Do?" *Foreign Broadcast Information Service Daily* (hereinafter *FBIS*) (March 26, 1984), pp. S1–S9, esp. S2 and S4.

4 "Nuclear Power Plants in the USSR: Operating, Under Construction, and Planned," *Energetik,* no. 3 (1978): 33.

5 Sinev, N. M., "Nuclear Power Engineering: Today and Tomorrow," *Nauka v SSSR,* no. 3 (1982): 50–63, esp. 53.

6 Kelly, W. J., Shaffer, H. L., and Thompson, J. K., "The Economics of Nuclear

Power in the Soviet Union," *Soviet Studies* 34, no. 1 (January 1982): 43–68, esp. 45–57.

7 Private U.S. industry source.

8 Marchuk, G., "Comprehensive Target Programs," *Ekonomicheskaya gazeta*, no. 1 (1983): 2.

9 "Development of Atomic Power Engineering," *Ekonomicheskaya gazeta*, no. 52 (1983): 2.

10 "Long-Term Main Directions of the Energy Program of the USSR," *Ekonomicheskaya gazeta*, no. 12 (1984): insert after 4.

11 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1985, no. W1323, A7.

12 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1985, no. W1323, A7.

13 Shashavin, G. A., Ignatenko, Ye. I., and Boldyrev, V. M., "Status and Prospects of the Development of NPS's with VVER (Reactors)," *Atomnaya energiya* 56, no. 6, 1984, pp. 353–359, esp. 354.

14 Petrosyants, A. M., *Sovremennyye problemy atomnoy nauki i tekhniki v SSSR* (Contemporary Problems of Atomic Science and Technology in the USSR) (Moscow: "Atomizdat," 1976) 3rd rev. ed., pp. 123, 171.

15 Shchelkin, K. I., *Sovetskaya atomnaya nauka i tekhnika* (Soviet Atomic Science and Technology) (Moscow: "Atomizdat," 1967). [Translated as JPRS 45,331, May 13, 1968, pp. 116–18.]

16 Petrosyants, A. M., et al., *Mirnyy atom v stranakh sotsializma* (The Peaceful Atom in the Countries of Socialism) (Moscow: "Atomizdat," 1979), p. 136.

17 "Fast Reactors to Be 800-MWe, Not 1600-MWe," *Nuclear News* (November 1981), p. 72.

18 Grigoryev, V. A., and Zorin, V. M., eds., *Teplovyye i atomnyye elektrostantsii, Spravochnik* (Thermal and Atomic Electric Stations, A Handbook) (Moscow: "Energoizdat," 1982), pp. 250, 261, and 277.

19 Aleksandrov, A. P., Kochenov, A. S., Kulov, Ye. V., Meshkov, A. G., Ryazantsev, Ye. P., and Sidorenko, V. A., "Nuclear Power Engineering in the USSR," *Atomnaya energiya* 54, no. 4 (1983): 243–49, esp. 246.

20 Dollezhal, N. A., Yemelyanov, I. Ya., Cherkashov, Yu. M., et al., "Some Features of and Operational Experience with NPS's with the RBMK-1000," *Atomnaya energiya* 54, no. 4 (1983): 257–62, esp. 258.

21 Sadoshenko, S., "The Firstborn Is Getting onto Its Feet," *Sotsialisticheskaya industriya* (January 16, 1983), p. 1.

22 "Power Production Shifts," *Eastwest Markets* (March 21, 1977), pp. 7–8.

23 "Construction of Atommash," *Trud* (March 20, 1976), p. 1.

24 Pershin, V., "Power Engineering: Eliminating the Disproportions," *Sotsialisticheskaya industriya* (January 30, 1981), p. 2. [Translated as JPRS 77,807, April 10, 1981, pp. 11–14.]

25 Krylov, A., "For Atomic Power Engineering," *Leningradskaya pravda* (November 22, 1980), p. 2.

26 "The Base of Atomic Machine Building," *Rabochaya gazeta* (January 3, 1981), p. 1.

27 Vorobyev, A., "Reactor Under the X-Ray," *Sotsialisticheskaya industriya* (October 27, 1982), p. 1.

28 "Reconstruction of the Izhora Plant," *Ekonomicheskaya gazeta*, no. 33 (1980): 1.

29 "Soviet Plans for Development of Atomic Power Industry," *Rynki Zagraniczne*, no. 20 (1980): 5. [Translated as JPRS 75,439, April 4, 1980, pp. 1–4.]

30 "Five-Year Plan Accelerates Nuclear Program," *Nuclear Engineering International* 26, no. 308 (1981): 4.

31 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1980, no. W1088, p. A10.

32 Doblenko, Ye., "Technical Problems of Atomic Machine Building," *Ekonomicheskoye sotrudnichestvo stran-chlenov SEV*, no. 6 (1982): 17–21, esp. 17.

33 *BBC Summary of World Broadcasts*, part 2: Eastern Europe (Weekly Economic Report), 1983, no. W1239, p. A17.

34 *BBC Summary of World Broadcasts*, part 2: Eastern Europe (Weekly Economic Report), 1981, no. W1166, p. A12.

35 Ludwig, J., "Skoda—the Most Important Industrial Partner," *Ekonomicheskoye sotrudnichestvo stran-chlenov SEV*, no. 2 (1983): 66–70, esp. 67.

36 "Large Nuclear Plant Castings," *Nova Svoboda*, no. 3 (1979): 12. [Translated as JPRS 74,890, November 13, 1979, p. 13.]

37 Matejka, F., and Zbiral, V., "Pumps for Nuclear Plants," *Czechoslovak Foreign Trade*, no. 1 (1982): 20–21.

38 "Czechoslovak-Soviet Cooperation in Power Engineering," *Czechoslovak Foreign Trade*, no. 5 (1982): 10–11.

39 *BBC Summary of World Broadcasts*, part 2: Eastern Europe (Weekly Economic Report), 1982, no. W1176, p. A20.

40 Margulova, T. Kh., *Atomnyye elektricheskiye stantsii* (Atomic Power Stations) (Moscow: Izd. "Vysshaya shkola," 1978), pp. 185, 295–97.

41 Akinfiyev, V. P., Gellerman, A. D., and Bronnikov, V. K., "Experience with Mastering the Rated Capacity of the First Phase of the Chernobyl NPS," *Elektricheskiye stantsii*, no. 2 (1980): 7–11, esp. 9.

42 Troyanovskiy, B. M., *Turbiny dlya atomnykh elektrostantsiy* (Turbines for Atomic Power Stations) (Moscow: Izd. "Energiya," 1978), pp. 79–85, esp. 79.

43 Voronin, L. M., Volkov, A. P., and Trofimov, B. A., "Experience with the Operation of and Performance of Start-up-and-Adjustment Work at the Kola NPS," *Elektricheskiye stantsii*, no. 7 (1980): 7–10, esp. 9.

44 Grigorash, G. I., "Turbogenerators of the Kharkov Plant 'Elektrotyazhmash' for NPS's," *Elektricheskiye stantsii*, no. 8 (1980): 5–8, esp. 5 and 7.

45 Khutoretskiy, G. M., and Trofimov, A. M., "The TVV-1000-4 Turbogenerator with Hydrogen-Water Cooling," *Elektricheskiye stantsii*, no. 3 (1980): 2–10, esp. 2.

46 Dienes, L., and Shabad, T., *The Soviet Energy System: Resource Use and Policies* (Washington, D.C.: V. H. Winston & Sons, 1979), pp. 188–89.

47 Smolin, V. N., Yesikov, V. I., Mityayev, Yu. I., and Vasilev, S. A., "Direct-Flow Scheme of Reactor with Smooth Tubular Fuel Elements for Load Following NPS," *Atomnaya energiya* 48, no. 1 (1980): 9–12, esp. 9.

48 Dollezhal, N. A., "Nuclear Power and Scientific-Technical Tasks of Its Advancement," *Atomnaya energiya* 44, no. 3 (1978): 203–12, esp. 206.

49 Rubin, V. B., "The Problem of the Load-Following Capability of Atomic Electric Stations," *Elektricheskiye stantsii*, no. 11 (1978): 5–7.

50 Gusev, V. N., and Rozova, V. I., "On the Possibility of the Operation of Atomic Electric Stations with a Variable Load," *Elektricheskiye stantsii*, no. 9 (1977): 9–11.

51 Samsonov, V. S., and Khaymov, G. M., "The Effectiveness of NPS's Under Daily Load-Reduction," *Elektricheskiye stantsii*, no. 1 (1980): 19–21.

52 Kazachkovskiy, O., "Condition and Outlook for Work to Create an NPS with Fast-Neutron Reactors," *Ekonomicheskoye sotrudnichestvo stran-chlenov SEV*, no. 2 (1980): 74–79, esp. 75–76 and 78 (accidents).

53 Doucette, D., "The Embattled Breeder Reactor," *High Technology* no. 7 (1983): 50–57, esp. 52.

54 Kazachkovskiy, O. D., Meshkov, A. G., Mitenkov, F. M., et al., "Development of and Operational Experience with Fast Reactors in the USSR," *Atomnaya energiya* 54, no. 4 (1983): 262–69, esp. 265.

55 Lepkowski, W., "USSR Reaches Takeoff in Nuclear Power," *Chemical and Engineering News* (November 6, 1978), pp. 31–36.

56 "World's Largest Fast-Neutron Nuclear Reactor Commissioned in the USSR," *Soviet Export*, no. 4 (1980): 13.

57 "Late Breeder in the Ural Mountains," *Wirtschaftswoche* (Düsseldorf) (May 2, 1980), pp. 14–16. [Translated as JPRS 75,973, July 2, 1980, pp. 8–10.]

58 Tropkin, A., "The Oil-Soaked Soil," *Soviet Life* (May 1980), pp. 24–28, esp. 26.

59 Akhmetov, R., "The Atomic Seventies," *Sovetskaya Moldaviya* (October 19, 1973), p. 4.

60 "Gas 'Arteries' of Reactors," *Sovetskaya Belorussiya* (February 7, 1981), p. 3.

61 Kiselevskiy, V. N., Tishchenko, S. S., Goltsev, V. P., Zavada, V. I., Karpenko, G. P., and Kolsov, A. S., "'Neytron-7' Unit for Reactor Tests of Structural Materials for Long-Term Strength and Creep in an Atmosphere of N_2O_4 Coolant," *Problemy prochnosti*, no. 3 (1979): 85–89, esp. 85.

62 Shasharin, G., "Atomic Power Engineering," *Planovoye khozyaystvo*, no. 10 (1984): 10–15, esp. 11.

63 "How Do We Manage to Avoid an Energy Crisis?" *Soviet Life*, no. 7 (1978): 24–27.

64 Koryakin, Yu. I., Baturov, B. B., Belostotskiy, A. M., et al., "Mathematical Modeling of the Developing Nuclear Power Generation," *Atomnaya energiya* 36, no. 6 (1974): 458–62.

65 Batayev, K., and Segal, M., "The Hot Atom," *Sotsialisticheskaya industriya* (June 5, 1980), p. 4.

66 "Use of Atomic Energy in USSR Discussed," *FBIS* 3, no. 43 (1976): U1.

67 "Nuclear Power Engineering to Be Developed," *FBIS* 3, no. 28 (1976): U1.

68 Protsenko, A. N., and Stolyarevskiy, A. Ya., "High-Temperature Nuclear Power Engineering—Trends of Long-Range Development," *Atomnaya energiya* 44, no. 6 (1978): 538–41.

69 Petrosyants, A. M., Aleksandrov, A. P., Dollezhal, N. A., and Leypunskiy, A. I., "Prospects for the Development of Atomic Energy in the Soviet Union," *Atomnaya energiya* 31, no. 4 (1971): 315–23, esp. 322.

70 U.S. Office of Technology Assessment, *Technology and Soviet Energy Availability* (Boulder, Colo.: Westview Press, 1982), p. 126.

71 Campbell, R. W., *Soviet Energy Technologies: Planning, Policy, Research and Development* (Bloomington: Indiana University Press, 1980), pp. 41, 50–61, 155–69.

72 "In the Presidium of the USSR Supreme Soviet," *Pravda* (July 20, 1983), p. 2.

73 "In the Presidium of the USSR Supreme Soviet," *Sotsialisticheskaya industriya* (August 2, 1983), p. 2.

74 Amann, R., and Cooper, J., eds., *Industrial Innovation in the Soviet Union* (New Haven and London: Yale University Press, 1982), p. 305.

75 Semenov, B. A., "Nuclear Power in the Soviet Union," *IAEA Bulletin* 25, no. 2 (1983): 47–59, esp. 53.

76 "Kirillin on Development of Nuclear Powerplants," *Archives of Biochemistry and Biophysics* (U.S.) (January 8, 1975).

77 "Soviet Official Outlines Progress in Nuclear Power Plants," *Asahi Shimbun* (November 11, 1977). [Translated as *FBIS* 3, no. 229 (1977): annex.]

78 Troitskiy, A., "Electric Power Engineering: Problems and Prospects," *Planovoye khozyaystvo*, no. 2 (1979): 18–25, esp. 20.

79 "TOKAMAK," *Bolshaya sovetskaya entsiklopediya* (Great Soviet Encyclopedia) (Moscow: Izd. "Sovetskaya Entsiklopediya," 1977), 3d ed., vol. 26, p. 33.

80 Velikhov, Ye. P., Kadomtsev, B. B., and Orlov, V. V., "Thermonuclear Synthesis and Nuclear Power Engineering," *Teploenergetika*, no. 11 (1977): 59–66, esp. 61.

81 Kadomtsev, B. B., and Yeliseyev, G. A., "Thermonuclear Power Stations Becoming a Reality," *Soviet Export*, no. 2 (1980): 30–33.

82 Makarova, T., "The 'Tokamak' Is Being Created," *Sotsialisticheskaya industriya* (July 14, 1983), p. 2.

83 Belyakov, V. P., Glukhikh, V. A., Kavun, A. M., et al., "The Tokamak T-15 Unit: Main Characteristics and Research Program," *Atomnaya energiya* 52, no. 2 (1982): 101–8, esp. 101–3 and 105.

84 "The Angara Experiment: Controlling a Thermonuclear Reaction" (an interview with Leonid Rudakov), *Soviet Union*, no. 11 (1978): 12–13.

85 Basov, N. G., "The Laser and Power Engineering of the Future," *Krasnaya zvezda* (July 2, 1983), p. 3.

86 Usoltsev, A., "Nuclear Fusion: How to Control It," *Sovetskaya Rossiya* (November 12, 1982), p. 4.

87 Kintner, E. E. (director, Office of Fusion Energy, U.S. Department of Energy), "A Review of International Fusion Research Programs," lecture presented at Battelle's Columbus Laboratories, Columbus, Ohio, January 4, 1982.

88 USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR, 1922–1982* (National Economy of the USSR, 1922–1982) (Moscow: Izd. "Finansy i statistika," 1982), p. 406.

89 Extrapolation of time trend shown in Shulgina, I. V., *Analiz nakladnykh raskhodov v nauchnykh uchrezhdeniyakh* (Analysis of Overhead Expenses in Scientific Institutions) (Moscow: Izd. "Finansy," 1974), p. 13.

90 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1231, p. A6.

91 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1238, p. A5.

92 Kuznetsova, T., "Meeting of the Scientific Council," *Leningradskaya pravda* (January 7, 1981), p. 3.

93 Struzhentsov, D., "Towards Power Engineering of the 21st Century," *Trud* (April 17, 1983), p. 3.

94 "Controlled Plasma," *Sovetskaya Kirgiziya* (June 30, 1981), p. 3.

95 Grechuk, N., "High Tension," *Vecherniy Leningrad* (November 6, 1981), p. 3.

96 Manilova, Zh., "To Kindle the Terrestrial Sun," *Leningradskaya pravda* (October 19, 1980), p. 2.

97 "Before the Start-Up of the 'Angara,'" *Leningradskaya pravda* (April 19, 1981), p. 2.

98 "Toward Thermonuclear Power Engineering," *Pravda* (September 15, 1981), p. 3.

99 Panov, D., "New Thermonuclear Installation," *Sovetskaya Latviya* (March 2, 1981), p. 4.

4 The Production of Crude Oil and Arctic Gas

1 USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR v 1983 g.* (National Economy of the USSR in 1983) (Moscow: Izd. "Finansy i statistika," 1984), pp. 152–53 (fuel and tube production), 394 (monthly wages in science).

2 "Decree of the CC of the CPSU," *Izvestiya* (December 2, 1980), pp. 1–7.

3 "Labor Strides of the Five-Year Plan," *Izvestiya* (January 29, 1984), p. 2.

4 "Let's Successfully Finish the Five-Year Plan," *Pravda* (January 26, 1985), p. 2.

5 Stanislavyuk, V. L., ed., *Razvitiye yedinoy transportnoy seti SSSR v desyatoy pyatiletke* (Development of a Single Transport Network in the USSR in the Tenth Five-Year Plan) (Moscow: Izd. "Transport," 1977), pp. 11, 118.

6 Vtorushin, S., and Murzin, A., "Tyumen Gas," *Pravda* (February 26, 1977), p. 2.

7 Vtorushin, S., and Murzin, A., "Tyumen Gas," *Pravda* (February 27, 1977), p. 2.

8 Galperson, Ye. B., "The Petroleum Industry in the Sixtieth Year of Soviet Power," *Ekonomika neftyanoy promyshlennosti*, no. 10 (1977): 6–13.

9 Wilson, D., *Soviet Oil & Gas to 1990* (London: The Economist Intelligence Unit Ltd., November 1980), pp. 55 (well depths), 67, 68, 84–85 (enhanced recovery), 96–97 (offshore).

10 Henry, W. M., "An Assessment of Emerging Foreign Technology in Geochemical Exploration," Report by Battelle's Columbus Laboratories, Columbus, Ohio, April 20, 1976.

11 Vetshteyn, V. Ye., Artemchuk, V. G., and Altshuler, P. G., "Behavior of Oxygen and Hydrogen Isotopes in Waters of Water-Oil Contact Zone: On the Example of the Pripyatskiy Depression and West Siberia," *Geokhimiya*, no. 4 (1981): 525–31.

12 Golyshev, S. I., and Ivanov, V. G., "Isotopic Composition of Hydrogen, Oxygen, and Carbon in the Ground Waters of the Southeastern Part of the West Siberian Oil and Gas Basin," *Geokhimiya*, no. 7 (1983): 1024–28.

13 Simkhayev, V. Z., Dadashev, R. M., Kitushina, I. A., and Sutovskiy, S. M., "A Petrogeochemical Method for Monitoring the Migration of Oil-Water Contact Zones and the Contours of Oil Reservoirs," *Azerbaydzhanskoye neftyanoye*

khozyaystvo, no. 12 (1982): 19–23.

14 Valitov, N. B., "Peculiarities of the Distribution of Sulfur in Oils Occurring in Carbonate and Terrigene Sediments (in Connection with Experimental Studies)," *Geokhimiya*, no. 3 (1983): 467–73.

15 Kurbskiy, G. P., Bogdanchikov, A. I., and Abushayeva, V. V., "The Character of Modification of Individual Hydrocarbon Compositions of Benzene Fractions of Oil in the Process of Biodegradation," *Geokhimiya*, no. 2 (1983): 294–301.

16 Kurbskiy, G. P., Bogdanchikov, A. I., Abushayeva, V. V., "The Character of the Modification of the Individual Hydrocarbon Composition of Benzene Fractions of Oil During the Process of Katagenesis," *Geokhimiya*, no. 1 (1983): 126–35.

17 Galimov, E. M., Koblova, A. Z., Frik, M. G., and Nigmatullina, F. S., "Isotopic Composition of Carbon in Individual n-Alkanes of Oils," *Geokhimiya*, no. 2 (1983): 302–5.

18 Beskrovnyy, N. S., Kudryavtseva, Ye. I., and Lobkov, V. A., "Carbon Isotopic Composition of the Natural Gases of Kamchatka," *Geokhimiya*, no. 11 (1975): 1660–67.

19 Chakhmakhchev, V. A., Lositskaya, I. F., Tikhomirov, V. I., and Semenova, R. A., "A Reflection of Katagenesis of Oils and Bitumoids in Their Microelement Compositions," *Geokhimiya*, no. 1 (1983): 152–56.

20 Chakhmakhchev, V. A., Punanova, S. A., Tverdova, R. A., Zharkov, N. I., and Ryabova, G. M., "Experimental Study of Modification of the Composition of Oil in the Process of Its Filtration Through Porous Media," *Geokhimiya*, no. 7 (1982): 1035–42.

21 Galimov, E. M., Geodekyan, A. A., Galimova, L. V., and Trotsyuk, V. Ya., "Formation of Petroliferous Zones in the Mid-Caspian Basin According to Data on Carbon Isotopic Composition," *Geokhimiya*, no. 7 (1975): 963–78. [Translated in *Geochemistry International* 12, no. 4 (1975): 1–14.]

22 Khitarov, N. I., "250th Anniversary of the USSR Academy of Sciences and Geochemistry," *Geokhimiya*, no. 5 (1974): 659–61.

23 Marshall, E., "Gains in Soviet Oil Reserves Doubted," *Science* (December 21, 1979), pp. 1379–82.

24 Morgenthaler, E., "Kremlin Crunch: Soviet Faces a Squeeze in Oil Needs by 1980s, Despite Huge Reserves," *Wall Street Journal* (January 9, 1978), pp. 1, 21.

25 U.S. Central Intelligence Agency, "Prospects for Soviet Oil Production: A Supplemental Analysis," July 1977, pp. 16, 20–22, 26.

26 Campbell, R. W., *Trends in the Soviet Oil and Gas Industry* (Baltimore: Resources for the Future, Inc./Johns Hopkins University Press, 1976), pp. 17–22.

27 Goldman, M. I., "Is There a Russian Energy Crisis?" *Atlantic Monthly* (September 1980), pp. 55–64.

28 Pavlov, V. I., Kuznetsov, K. A., and Umanchik, N. P., "Oil Industry Machine Building," *Khimicheskoye i neftyanoye mashinostroyeniye*, no. 11 (1977): 18–22.

29 Orel, B. Ye., Afanasyev, Yu. T., Ovodov, N. Ye., and Letavin, A. I., "Basic Results of Superdeep Drilling in the USSR in 1975–1980 and Work Prospects for the 11th Five-Year Plan," *Geologiya nefti i gaza*, no. 8 (1983): 18–22.

30 Campbell, R. W., *The Economics of Soviet Oil and Gas* (Baltimore: Resources for the Future, Inc./Johns Hopkins University Press, 1968), pp. 106–14.

31 Mishchevich, V. I., "Drilling Operations in the USSR for 60 Years," *Neftyanoye khozyaystvo*, no. 10 (1977): 24–30. [JPRS translation available.]

32 McCray, A. W., and Cole, F. W., *Oil Well Drilling Technology* (Norman: University of Oklahoma Press, 1959), pp. 186–87, 189–96.

33 Chelombiyev, B. K., "Experiences of the 'Stravropolneftegaz' Association in Raising the Efficiency of Drilling," *Organizatsiya i upravleniye neftyanoy promyshlennosti*, no. 8 (1979): 12–16.

34 Maltsev, N. A., "New Frontiers of the USSR Oil Industry," *Neftyanoye khozyaystvo*, no. 9 (1979): 5–10.

35 Rizvanov, N. M., Kagarmanov, N. F., and Balandin, P. S., "Application of Various Drilling Methods in Bashkiria," *Bureniye*, no. 6 (1982): 4–5.

36 Ioanesyan, Yu. R., Matsiyevskiy, V. P., Simonyants, S. L., and Petruk, N. V. "On Rotary and Turbine Methods of Drilling," *Neftyanaya i gazovaya promyshlennost*, no. 3 (1983): 21–24.

37 Mishchevich, V. I., "Technical Progress in Deep Drilling," *Neftyanoye khozyaystvo*, no. 5 (1975): 16–18.

38 "Soviet Drillbit Plant Construction Snarled," *Oil and Gas Journal*, (December 10, 1979), p. 142.

39 Lee, J. R., and Lecky, J. R., "Soviet Oil Developments," in U.S. Congress, Joint Economic Committee, *Soviet Economy in a Time of Change* (Washington, D.C.: U.S. Government Printing Office, 1979), vol. 1, pp. 581–99.

40 U.S. Central Intelligence Agency, "Prospects for Soviet Oil Production," April 1977, p. 5.

41 "Dresser Industries Loses License to Export Oilfield Technology to the Soviet Union," *Wall Street Journal* (December 4, 1980), p. 35.

42 Confidential industry source.

43 Petrov, V. V., "The Drillers of Checheno-Ingushetiya in the Struggle for Technical Progress," *Neftyanoye khozyaystvo*, no. 10, (1977): 67–70.

44 Dadashev, N., "An Important Reserve for Deep Drilling," *Vyshka* (October 20, 1978), p. 2.

45 Cumming, J. D., *Diamond Drill Handbook* (Toronto: J. K. Smit & Sons, 1956), pp. 392–93.

46 Kopylov, V. Ye., Chistyakov, Yu. A., and Mukhin, E M., *Vibratsii pri almaznom burenii* (Vibrations in Diamond Drilling) (Moscow: Izd. "Nedra," 1967).

47 Katsman, F. M., "Improving the Technical-Economic Indexes of Super-Deep Drilling," *Organizatsiya i upravleniye neftyanoy promyshlennosti*, no. 8 (1979): 19–22.

48 Abramson, M., and Pozdnyakov, V., "The Series IAN Bits Are Also Effective for Turbine Drilling," *Neftyanik*, no. 9 (1977): 10–11.

49 *Pravda Ukrainy* (January 13, 1980), p. 2.

50 Petrov, N., and Tairov, L., "They Have Gotten Stronger," *Pravda* (March 8, 1979), p. 2.

51 Shamayev, K., "Despite Difficulties," *Vyshka* (March 4, 1978), p. 2.

52 Yalymov, V. M., Berko, N. Ya., Struts, V. S., and Samoshkin, Yu. N., "Improving the Technology of Deep Drilling in the Oilfields of the Nizhnevolzhskneft Association," *Bureniye*, no. 10 (1977): 36–38.

53 Sedov, V. A., Yedeshko, L. N., and Golovchenko, A. B., "Extending the Life of Drill Collars," *Neftyanaya i gazovaya promyshlennost*, no. 3 (1983): 24–25.

54 Mishchevich, V. I., "The Development of Drilling Work," *Neftyanoye khozyaystvo*, no. 9 (1979): 10–13.

55 Aganbegyan, A., "Problems and Judgments: Siberia's Fuel," *Pravda* (August 1, 1983), pp. 1–2. [Translated as JPRS 84,421, September 28, 1983, pp. 1–7.]

56 Safiullin, M., "Where Metal 'Flies,'" *Pravda* (February 28, 1978), p. 2.

57 Kelly, W. J., *Directory of Selected Production Facilities in the Soviet Union*, directory prepared by Battelle's Columbus Division, Columbus, Ohio, January 10, 1986, pp. 17, 85–86.

58 Mamedov, S., Samedov, S., and Goltsev, V., "Why Did the Drillers Give Up Their Positions?" *Vyshka* (July 14, 1982), p. 2. [Translated as JPRS 82,088, October 27, 1982, pp. 19–21.]

59 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1979, no. W1031, p. A17.

60 Rudoiskatel, V., "Interdepartmental Boundary," *Ekonomicheskaya gazeta*, no. 31 (July 1979): 18.

61 Gorkov, A. P., and Lisovskaya, G. F., "Analysis of Estimated Costs of Drilling and Ways of Reducing Them in the 'Ukrneft' Association," *Ekonomika neftyanoy promyshlennosti*, no. 5 (1976): 7–11.

62 Anikeyev, G., "The New Drilling Rigs Uralmash-4000D-1 and Uralmash-4000E-1," *Neftyanik*, no. 8 (1983): 10–11. [Translated as JPRS-UEN-84-001, January 3, 1984, pp. 26–28.]

63 Rudoiskatel, V. V., and Vladimir, V. I., "The Machine Builders of Uralmashzavod to the Oilmen," *Neftyanoye khozyaystvo*, no. 11 (1977): 3–6.

64 Sherstnev, A., "'Extra-Plan' Innovation," *Sovetskaya Rossiya* (December 11, 1977), p. 2.

65 U.S. Library of Congress, *Glossary of Russian Abbreviations and Acronyms* (Washington, D.C.: U.S. Government Printing Office, 1967), p. 107.

66 Paliy, P. A., and Nikishin, V. A., "VNIIBT—25 years," *Neftyanik*, no. 6 (1978): 20–21.

67 Interview with A. A. Asan-Nuri and other specialists of VNIIBT, *Neftyanoye khozyaystvo*, no. 6 (1978): 3–11. [Translated as JPRS 71,825, September 7, 1978, pp. 24–36.]

68 Golovastikov, N., "In the Bowels of the Earth," *Leninskoye znamya* (February 7, 1979), p. 4.

69 "PGB Packers to Hermetically Seal Casing String Shoe," *Gazovaya promyshlennost*, no 5 (1979): back cover.

70 Terentyev, Yu. G., "The Development of Organization of Production, Labor, and Management in the Drilling of Oil Wells," *Organizatsiya i upravleniye neftyanoy promyshlennosti*, no. 10 (1977): 7–11.

71 USSR Ministry of Communication, *Spravochnik telefonov nauchnykh, uchebnykh i doshkolnykh uchrezhdeniy* (Directory of Telephones of Scientific, Educational, and Preschool Institutions) (Moscow: Izd. "Svyaz," 1977), p. 23.

72 U.S. Central Intelligence Agency, "Directory of Soviet Research Organizations," March 1978, p. 161.

73 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1978, no. W979, p. A17.

74 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1978, no. W997, p. A10.

75 "Baku Innovation," *Ekonomicheskaya gazeta*, no. 24 (June 1977): 16.

76 Ott, J. H., and Wise, R. A., "A Survey and Evaluation of Foreign Technology in the Enhanced Recovery of Petroleum," Report by Battelle's Columbus Laboratories, Columbus, Ohio, June 1975.

77 Maltsev, N. A., "The Application of Surface Active Agents in the Oil Industry," *Neftyanoye khozyaystvo*, no. 7 (1976): 3–7.

78 Petrukhin, A., "Mastering Oil Strata," *Sotsialisticheskaya industriya* (July 16, 1980), p. 2.

79 Committee on Enhanced Recovery, *Enhanced Oil Recovery: An Analysis of the Potential for Enhanced Oil Recovery from Known Fields in the United States—1976 to 2000* (Washington, D.C.: National Petroleum Council, 1976), p. 12.

80 "The Possibilities of an Oil Strata," *Ekonomicheskaya gazeta*, no. 8 (February 1983): 2. [Translated as JPRS 83,870, July 12, 1983, pp. 12–17.]

81 Umanskiy, L. M., and Titova, N. I., "The Development and Economic Effectiveness of Application of Secondary Methods for Recovering Oil in the Chechen-Ingush ASSR for 30 Years," *Ekonomika neftyanoy promyshlennosti*, no. 8 (1977): 25–28.

82 Baybakov, N. K., and Garushev, A. R., *Teplovyye metody razrabotki neftyanykh mestorozhdeniy* (Thermal Methods of Developing Petroleum Deposits) (Moscow: Izd. "Nedra," 1977), chaps. 1, 5.

83 Alekseyev, P. D., "A Revision of Wholesale Prices for Oil," *Neftyanoye khozyaystvo*, no. 11 (1975): 6–7.

84 Baranovskiy, M. I., Volkov, Yu. S., and Ovseyenko, G. I., "A Mathematical-Economic Method for Analyzing a Forecast of the Costs for Recovering Crude Oil and Gas," *Ekonomika neftyanoy promyshlennosti*, no. 5 (1975): 17–21.

85 "Soviet Hopes for West Siberian Oil Flow Clouded," *Oil and Gas Journal* (January 3, 1983), p. 54.

86 Shchelkachev, V. N., "Regularity of Change in the Cost of Extracting Oil as a Function of the Water Cut of the Wells: The Economics of Forced Extraction," *Neftyanoye khozyaystvo*, no. 1 (1979): 7–11.

87 Mekhtiyev, O., "More Attention to Secondary Methods," *Vyshka* (August 5, 1983), p. 2. [Translated as JPRS 84,920, December 12, 1983, pp. 38–41.]

88 Shashin, V., "A Strategy of Effectiveness," *Sotsialisticheskaya industriya* (August 28, 1975), p. 2.

89 Svishchev, M., and Koryagin, I., "Toward Greater Efficiency: How Much Can A Well Yield?" *Pravda* (June 7, 1976), p. 2.

90 Sorokin, V. A., "Evaluation of Prospects of Using New Methods for Raising the Petroleum Yield of Strata in Checheno-Ingush ASSR," *Neftyanoye khozyaystvo*, no. 3 (1979): 27–30.

91 U.S. Office of Technology Assessment, *Technology and Soviet Energy Availability* (Boulder, Colo.: Westview Press, 1982), pp. 52–53.

92 "New Azerbaijan Gaslift Valves," *Vyshka* (September 7, 1983), p. 1. [Translated as JPRS 84,920, December 12, 1983, p. 55.]

93 Li, G. S., Nigay, Yu. V., and Kabırov, M. M., "Operation of Water-Flooded Wells by the Gas-Lift Method," *Neftyanoye khozyaystvo*, no. 10 (1983): 49–51. [Translated as JPRS 84,920, December 12, 1983, pp. 30–34.]

94 Piyakov, G. N., Usenko, V. F., Kudashev, R. I., and Pavlov, V. P., "Investigation of the Effectiveness of Applying an Aqueous Solution of OP-10 in the Late Stage of a Waterflood," *Neftyanoye khozyaystvo*, no. 11 (1983): 43–46.

95 Gadzhiyev, B., "With the Help of Fire and Water," *Sotsialisticheskaya industriya* (July 8, 1978), p. 2.

96 Estrin, M., "Petroleum Extracted by Polymers," *Izvestiya* (August 18, 1978), p. 2.

97 "Soviets Push to Maintain Increases in Oil Output," *Oil & Gas Journal* (December 31, 1979), pp. 35–38.

98 "Surfactant Complex," *Soviet Business and Trade* (January 31, 1979), pp. 1–2.

99 Timonin, V., "Difficult Oil," *Pravda* (September 18, 1979), p. 2.

100 Katelkina, T., "The Important Buzachi Oil," *Narodnoye khozyaystvo Kazakhstana*, no. 6 (1983): 15–17. [Translated as JPRS 84,591, October 24, 1983, pp. 1–6.]

101 "The Petroleum Reservoir's Potential," *Vyshka* (March 14, 1979), p. 1.

102 "The Goal—A High Yield from Oil Strata," *Vyshka* (February 11, 1978), pp. 2–3.

103 Lalayants, A., "The Second Life of an Oil Field," *Sotsialisticheskaya industriya* (September 11, 1976), p. 2.

104 Wells, K., "Firms Hopeful on Procedures to Reclaim Oil," *Wall Street Journal* (September 25, 1984), p. 37.

105 Rigassi, D. A., "USSR Becomes the World's Leading Oil Producer," *World Oil* (August 15, 1975), pp. 121–36, esp. 126.

106 Photograph caption, *Pravda* (August 20, 1977), p. 2.

107 Troyan, S., "Gas from the Bottom of the Black Sea," *Izvestiya* (April 23, 1983), p. 1. [Translated as JPRS 83,954, July 21, 1983, pp. 22–23.]

108 *Arbeider-Bladet* (Oslo) (October 8, 1982), p. 11. [Translated as JPRS 82,280, November 19, 1982, p. 1.]

109 Kasyukov, I., "Oil Flows from the Baltic," *Izvestiya* (March 4, 1983), p. 1. [Translated as JPRS 83,954, July 21, 1983, pp. 24–26.]

110 Bakke, D. R., "New Tools May Boost USSR's Output," *Offshore* (June 20, 1980), pp. 178–79.

111 "Offshore Crude, Gas Production Increase," *Offshore* (July 20, 1984), pp. 52, 57, 58.

112 Kremer, V., and Melikov, D., "Apsheron's Subsoil Has Not Grown Scanty," *Sotsialisticheskaya industriya* (October 22, 1982), p. 2. [Translated as JPRS 82,568, December 30, 1982, pp. 12–16.]

113 Dzhafarov, A. M., and Samarskiy, V. N., "Jackup Drilling Rigs," *Mashiny i neftyanoye oborudovaniye*, no. 8 (1978): 17–20.

114 "1983 Offshore Rig Register," *Offshore* (August 1983), pp. 52, 54 (drill ships), 54, 56, 70, 77, 89, 92 (jackups), 98, 107 (semisubmersibles).

115 "Caspian Sea Yields More Oil for Soviet Union," *Oil and Gas Journal* (May 9, 1983), p. 78.

116 "Mobile Rig Update," *Offshore* (June 1984), p. 15.

117 Taitov, L., "For Oil in the Ocean Depths," *Pravda* (October 3, 1982), p. 1. [Translated as JPRS 82,568, December 30, 1982, pp. 20–21.]

118 "Tested for Strength," *Vyshka* (August 26, 1977), p. 1.

119 "Offshore Rig Report," *Offshore* (January 1981), pp. 112, 113, and 126.

120 "International Briefs," *Oil & Gas Journal* (December 19, 1983), p. 60.

121 "New Jackup on the Caspian," *Azerbaydzhanskoye neftyanoye khozyaystvo*, no. 12 (1982): 57.

122 Gadzhiyev, R. A., Samedov, F. S., Sarkisov, V. G., Tairli, Z. M., and Tripolskiy, M. Ya., "Problems of Improving Methods for Designing Fixed Offshore Platforms," *Azerbaydzhanskoye neftyanoye khozyaystvo*, no. 12 (1982): 51–54.

123 "USSR Orders Two Jack Ups from Rauma-Repola," *Oil & Gas Journal* (January 24, 1983), p. 32.

124 "1979 Oil and Gas Projects," *Soviet Business and Trade* (January 17, 1979), pp. 1–2.

125 "Accreditations," *Soviet Business and Trade* (January 3, 1979), pp. 3–4.

126 Photograph caption, *Sovetskaya Kirgiziya* (August 23, 1979), p. 2.

127 "Drillers Prepare to Put to Sea," *Sovetskaya Rossiya* (July 8, 1980), p. 1.

128 "The First of the Series," *Pravda* (June 23, 1980), p. 1.

129 Goldenberg, A., "'Shelf-1' on Duty," *Vyshka* (February 10, 1982), p. 1. [Translated as JPRS 80,652, April 23, 1982, pp. 87–88.]

130 Alekseyev, A., "Drilling Rig Will Put to Sea," *Sotsialisticheskaya industriya* (August 14, 1980), p. 6. [Translated as JPRS 76,943, November 3, 1980, pp. 57–59.]

131 Nechipurenko, O., "Before Putting Out to Sea," *Vyshka* (September 14, 1982), pp. 1–2. [Translated as JPRS 82,491, December 17, 1982, pp. 19–21.]

132 "The Semisubmersible Drilling Rig 'Shelf-2,'" *Azerbaydzhanskoye neftyanoye khozyaystvo*, no. 12 (1982): 54–56.

133 Photograph caption, *Sotsialisticheskaya industriya* (April 14, 1983), p. 1.

134 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1982, no. W1211, pp. A6 (Vyborg Shipyard) and A9 (experimental pipeline).

135 "A Drilling Rig Above the Waves," *Sotsialisticheskaya industriya* (March 30, 1978), p. 4.

136 "Finnish Drill Ships," *Soviet Business and Trade* (May 9, 1979), pp. 1–3.

137 Chebakov, V., "To Stand on a Spot," *Pravda* (July 2, 1983), p. 6.

138 Ryabchikov, V., "The Geologists Went to Sea," *Pravda* (June 19, 1983), p. 2.

139 "Deepwater Wells Survey," *Offshore* (June 1984), pp. 75–86, esp. 76.

140 Gaziyev, A., "To Grow 'Steel Islands' in the Sea," *Vyshka* (February 2, 1978), p. 1.

141 "Mitsubishi to Sign Contract on Baku Plant," *Business and Trade* (February 27, 1980), pp. 1–2.

142 Bezzhonov, V., "Gains from Concentration," *Sotsialisticheskaya industriya* (August 23, 1978), p. 2.

143 "A Floating Factory," *Sovetskaya Rossiya* (July 26, 1977), p. 1.

144 Kurdyukov, V., "Trimaran Leaves the Slip," *Trud* (June 25, 1977), p. 4.

145 Melikov, D., "For the Oilmen of the Sea," *Sotsialisticheskaya industriya* (May 20, 1978), p. 2. [Translated as JPRS 71,469, July 14, 1978, p. 23.]

146 Nikolayev, Ye., "For the Mastery of the Ocean," *Leningradskaya pravda* (Feb-

ruary 29, 1980), p. 1.

147 Iskov, K., "Underwater Lightning," *Sotsialisticheskaya industriya* (April 14, 1977), p. 4.

148 Barsov, V., "Scientists Confer," *Vodnyy transport* (November 28, 1978), p. 4.

149 "Soviets Halt Decline in Caspian Sea Production," *Oil & Gas Journal* (August 20, 1984), pp. 70, 72.

150 Kuhl, P. L., "The Soviet Gas Industry," *Soviet Business and Trade* (March 28, 1979), pp. 8–10.

151 Mufson, S., "Anatomy of Continuing Soviet Pipeline Controversy," *Wall Street Journal* (August 31, 1981), p. 27.

152 Dervota, V. A., Spiridonov, V. V., and Gekhman, A. S., "Laying Pipeline in the Tundra North of the Arctic Circle," *Stroitelstvo truboprovodov*, no. 5 (1975): 32.

153 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1982, no. W1204, p. A9.

154 Mufson, S., "U.S. Effort to Block Soviet Gas Pipeline Recalls Failed Embargo of 20 Years Ago," *Wall Street Journal* (July 14, 1982), p. 28.

155 Dienes, L., and Shabad, T., *The Soviet Energy System* (Washington, D.C.: V. H. Winston & Sons, 1979), pp. 90–91.

156 "System of Trunk Gas Pipeline of the Soviet Union (Beginning of the Eleventh Five-Year Plan)," *Stroitelstvo truboprovodov*, no. 2 (1981): insert following 20.

157 "Soviet Arctic Yields Big Hydrocarbons," *Oil & Gas Journal* (January 10, 1983), pp. 39–40.

158 Voznyak, V., "Increasing the Effectiveness of Gas Pipeline Construction," *Voprosy ekonomiki*, no. 4 (1983): 74–84, esp. 75.

159 Putintsev, A., "The Siberia-Western Europe Gas Pipeline Has Been Built Ahead of Schedule," *Soviet Life* (February 1984), p. 57.

160 *Stroitelstvo truboprovodov*, no. 12 (1982): insert following 24.

161 Shcherbin, B. Ye., "Main Highways of Fuel Power Engineering," *Stroitelstvo truboprovodov*, no. 12 (1982): 6.

162 "On the Central Committee's Draft Main Directions for the Development of the USSR National Economy in 1976–1980," *Pravda* (December 14, 1975), p. 3.

163 Speech by L. I. Brezhnev to the November 16, 1981, Plenum of the Central Committee of the Communist Party of the USSR, *Izvestiya* (November 17, 1981), p. 2.

164 Kolpakov, S. V., Pozhivanov, A. M., and Yugov, P. I., "Development and Wide Industrial Introduction of Complex Technology for Production of Steel and Skelp for Electrowelded Large-Diameter Oil and Gas Tubes," *Metallurg*, no. 9 (1981): 18.

165 Lyakishev, N. P., et al., "New Low-Perlite Steel 09G2FB for 1420-mm Diameter Trunk Gas Pipelines," *Stal*, no. 4 (1980): 327.

166 Shalimov, A. G., et al., "Production of High-Strength, Cold-Resistant Steels for Large-Diameter Gas Pipe," *Metallurg*, no. 12 (1979): 21–25, esp. 21.

167 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1981, no. W1115, p. i.

168 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1976, no. W909, p. A13.

169 "Growing Business for Rolls-Royce Industrial-Marine," *SBAC News* (London), no. 108 (1977): 4.

170 "Advance of the Five-Year Plan," *Izvestiya* (January 23, 1983), p. 2.

171 Pogorzhelskiy, V. I., Babitskiy, M. S., Klimenko, V. M., Khromov, V. D., Nosochenko, O. V., Kurdin, A. Ya., "Assimilation of Controlled Rolling of Skelp for Gas Pipeline Tubes on the 3600 Mill at the 'Azovstal' Plant," *Stal*, no. 3 (1980): 209–11.

172 Ivantsov, O. M., "Problems of Northern Main Gas Pipelines," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 4 (1979): 12.

173 Bokserman, Yu., "Ways to Increase the Efficiency of Fuel Transport," *Planovoye khozyaystvo*, no. 10 (1977): 94–102, esp. 97.

174 Bokserman, Yu., "Look to the Future," *Oktyabr*, no. 13 (1977): 169–78. [Translated as JPRS 70,661, February 21, 1978, pp. 9–20, esp. 18.]

175 Noskov, V., "There are Laminated Pipes," *Sotsialisticheskaya industriya* (August 21, 1982), p. 1.

176 Rigassi, D. A., "Soviets Continue to Expand Crude, Products Systems," *Pipe Line Industry* (January 1983), p. 60.

177 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1982, no. W1212, p. A10.

178 "For Powerful Gas Pipelines," *Sotsialisticheskaya industriya* (May 17, 1981), p. 2.

179 Ivantsov, O. M., "Arctic Pipeline Construction in the Soviet Union—Part I," *Pipeline and Gas Journal* (September 1978), pp. 48–58, esp. 50.

180 "Technology and Means of Building 1420-mm Diameter Pipelines With 10 Megapascal Pressure," *Stroitelstvo truboprovodov*, no. 4 (1982): 34–35.

181 Rybalchenko, V., "Sketch of the Paton Institute Workers," *Sotsialisticheskaya industriya* (April 25, 1982), p. 2.

182 Petrenko, V., "Serve, Steel, Without Fatigue," *Pravda Ukrainy* (July 9, 1981), p. 2.

183 Paton, B. Ye., "Solution of Problems of Scientific-Technical Progress in Pipeline Construction," *Stroitelstvo truboprovodov*, no. 12 (1982): 19–23.

184 Paton, B. Ye., and Medovar, B. I., "Problems of Metallurgy of the Future," *Budushcheye nauki*, no. 14, (1981): 7–14.

185 Dertsakyan, A. K., "Central Projects of the Five-Year Plan," *Stroitelstvo truboprovodov*, no. 2 (1982): 5.

186 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1981, no. W1130, p. A14.

187 Velikanov, G. F., "Eleventh Five-Year Plan of the Nevskiy Machine Builders," *Energomashinostroyeniye*, no. 12 (1981): 4.

188 Neuymin, M. I., "Development of Gas Turbine Building in the USSR," *Gazovaya promyshlennost*, no. 11 (1977): 44.

189 "They Help the Siberians," *Pravda* (April 5, 1981), p. 3.

190 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1263, p. A12.

191 Wilson, D., "U.S. Opposition Won't Delay Russian Gas Line," *Pipe Line Industry* (November 1982), pp. 65–74, esp. 74.

192 "The Kremlin Shrugs Off Snarls in the Pipeline," *Business Week* (April 18, 1983), p. 52.

193 Podberezin, O. L., Osipenko, V. N., and Proskuryakov, G. V., "New Gas-Pumping Unit with 16-MW Capacity," *Energomashinostroyeniye*, no. 2 (1983): 2–5.

194 "Controversy Building Over U.S. Sanctions Against Yamal Pipeline," *Oil & Gas Journal* (August 16, 1982), p. 45.

195 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1981, no. W1163, p. A14.

196 Ukhov, Ye., "Ground Routes of Aviation Motors," *Trud* (October 6, 1982), p. 1. [Translated as JPRS 82,910, February 22, 1983, p. 87.]

197 *Vozdushnyy transport* (December 8, 1983), p. 3.

198 Yakovlev, A. I., Ishutin, N. A., Tverdokhlebov, V. I., and Volkov, B. M., "Gas Pumping Units with Marine Drives," *Gazovaya promyshlennost*, no. 4 (1983): 2–3.

199 Maliyenko, A., "Units for Gas Pipelines," *Pravda Ukrainy* (July 30, 1982), p. 2.

200 Agapkin, V. M., "Increase the Effectiveness of the 'Sever-1' Complexes," *Stroitelstvo truboprovodov*, no. 10 (1981): 24.

201 Andronikov, A. V., "Operation of the 'Styk-1' Complex," *Stroitelstvo truboprovodov*, no. 11 (1980): 28.

202 Zinevich, A. M., "Increasing the Reliability of Pipelines Being Built in the Regions of Western Siberia," *Stroitelstvo truboprovodov*, no. 9 (1982): 6.

203 Rigassi, D., "Soviet Union Continues Huge Expansion Program," *International Pipeline Industry* (November 1978), p. 113.

204 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1982, no. W1191, p. A6.

205 Bokserman, Yu., "From the Oil Fields to the Consumer," *Sotsialisticheskaya industriya* (August 1, 1975), p. 2.

206 Shcherbin, B. Ye., "For Great Construction Effectiveness," *Ekonomicheskaya gazeta*, no. 6 (1976): 9.

207 Zinevich, A. M., "Contribution to the Development of the Branch Science of Pipeline Construction," *Stroitelstvo truboprovodov*, no. 11 (1977): 7.

208 "Soviets Add Jack Up to Caspian Sea Fleet," *Oil & Gas Journal* (December 26, 1983), p. 66.

209 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1984, no. W1315, p. A5.

5 Options for the Use of Eastern Lignite and Sub-Bituminous Coal

1 Kelly, W. J., Shaffer, H. L., and Spengler, T. P., "Coal and Oil Shale R&D in the Soviet Union," report prepared for the Lawrence Livermore National Laboratory, Livermore, Calif., by Battelle's Columbus Laboratories, Columbus, Ohio, November 30, 1981.

2 U.S. Office of Technology Assessment, *Technology and Soviet Energy Availability* (Boulder, Colo.: Westview Press, 1982), pp. 81–108.

3 Dienes, L., and Shabad, T., *The Soviet Energy System* (Washington, D.C.: V. H. Winston & Sons, 1979), pp. 110–11.

4 "Labor's Strides in the Five-Year Plan," *Izvestiya* (January 29, 1984), p. 2.

5 "Let's Successfully Finish the Five-Year Plan," *Pravda* (January 26, 1985), p. 2.

6 "Draft Main Directions for Development of the National Economy of the USSR for 1981–85 and the Period to 1990," *Pravda* (December 2, 1980), pp. 1–6.

7 "News Notes," *Soviet Geography: Review and Translation* (April 1983), p. 321.

8 U.S. Office of Technology Assessment, "Technology and Soviet Energy Availability," (Washington, D.C.: U.S. Government Printing Office, November 1981), p. 84.

9 Interview with Coal Minister B. F. Bratchenko, *Ekonomicheskaya gazeta*, no. 7 (1982): 1–2.

10 USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR v 1982g.* (National Economy of the USSR in 1982) (Moscow: Izd. "Finansy i statistika," 1983), p. 143.

11 "On Additional Measures for Accelerating the Development of Coal Surface Mining in 1981–1990," *Sobraniye postanovleniy Pravitelstva SSSR*, no. 27 (1981): 675–680, esp. 677.

12 "USSR Coal Industry in 1977," *Ugol*, no. 4 (1978): 70.

13 Sizov, L., "Siberia's Fuel Base," *Trud* (June 27, 1980), p. 2.

14 Ovchinnikov, V. "Power of Ekibastuz," *Stroitelnaya gazeta* (March 26, 1980), p. 2.

15 Tyzhnov, A. V., "Geological Reserves of Coal in the USSR," *Sovetskaya geologiya*, no. 4 (1970): 54–65, esp. 57.

16 Shelest, V. A., *Regionalnyye energoekonomicheskiye problemy SSSR* (Regional Energy Economic Problems of the USSR) (Moscow: Izd. "Nauka," 1975), p. 113.

17 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1246, p. A7.

18 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1261, p. A7.

19 Melnikov, N., and Shelest, V., "Fuel and Energy Complex of the USSR," *Planovoye khozyaystvo*, no. 2 (1975): 8–19, esp. 11.

20 Sidorenko, A. V., ed., *Gornaya nauka i ratsionalnoye ispolzovaniye mineralno-syryevykh resursov* (Mining Science and the Rational Use of Mineral and Raw Material Resources) (Moscow: Izd. "Nauka," 1978), p. 47.

21 Mazover, Ya., "The Future of the Kansk-Achinsk Coal Basin," *Planovoye khozyaystvo*, no. 6 (1975): 65–73.

22 Fedirko, P., "Looking Into the Far Future," *Trud* (November 10, 1976), p. 2.

23 Kuzyukov, F., "Siberia's Fuel Storehouse," *Tekhnika i molodezhi*, no. 11 (1977): 4–6, esp. 4.

24 Lir, Yu. S., and Zhigulenkova, A. I., *Ekonomika dobychi, pererabotki i ispolzovaniya burogo uglya* (Economics of the Extraction, Processing, and Use of Brown Coal) (Moscow: Izd. "Nedra," 1981), p. 61.

25 Sergeyev, A., "KATEK: The Forecasts and the Present," *Tekhnika i nauka*, no. 1 (1977): 4–8.

26 Grigoryeva, Ye. A., "Hydrogenation of Brown Coals of the Individual Deposits of the Kansk-Achinsk Basin," *Khimiya tverdogo topliva*, no. 1 (1983): 114–20.

27 Krichko, A. A., and Semenov, L. V., "New Directions in Chemical Processing of Kansk-Achinsk Basin Coals," *Ugol*, no. 12 (1975): 62–66.

28 Chukhanov, Z. F., Nikolayev, A. M., Karasev, V. A., and Kalyuzhny, V. V., "The Integrated Use of Brown Coals by the Combined Heat-Carrier Method (Sum-

mary)," United Nations, Economic Commission for Europe, Seminar on Technologies for the Utilization of Low-Calorie Fuels, Varna, Bulgaria, April 20–22, 1976, SC./TECH/SEM.5/R.14, March 9, 1976, esp. pp. 1, 3.

29 Zhimerin, D., "The Fuel-Energy Balance Examined," *Pravda* (December 17, 1976), p. 2.

30 Probst, A., "Ways of Developing the Fuel Economy of the USSR," *Voprosy ekonomiki*, no. 6 (1971): 51–63.

31 U.S. Central Intelligence Agency, "USSR: Coal Industry Problems and Prospects" (March 1980), p. 15.

32 Krichko, A., "Accomplishments in Coal Liquefaction," *Rabochaya gazeta* (May 24, 1977), p. 2.

33 Bogdanovsky, G., "Kuzbas Today and Tomorrow," *Moscow News*, no. 7 (1983): 12.

34 Yerkina, L. I., Ibragimov, D. Yu., Kirsanova, O. P., Krapchin, I. P., Feygin, S. A., and Frolova, T. Ye., "Economic Effectiveness of Substitution of Coal for Liquid Boiler Fuel at Power Stations in the European Part of the USSR," *Khimiya tverdogo topliva*, no. 4 (1978): 15–19.

35 "The Pavlodar-Ekibastuz Complex," *Ekonomicheskaya gazeta*, no. 22 (1978): 2.

36 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1262, p. A6.

37 "News Notes," *Soviet Geography: Review and Translation* (March 1981), p. 212.

38 "A Giant of Power Engineering," *Izvestiya* (February 25, 1978), p. 2.

39 "A Constellation of Industry," *Izvestiya* (April 7, 1979), p. 3.

40 "Kansk-Achinsk Fuel and Power Complex (KATEK)," *Ekonomicheskaya gazeta*, no. 2 (1983): 2.

41 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1235, p. A9.

42 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1980, no. W1074, p. A16.

43 Singer, J. J., ed., *Combustion, Fossil Fuel Systems* (A Reference Book on Fuel Burning and Steam Generation) (Windsor, Conn.: Combustion Engineering, 1981), 3rd ed., pp. 2–3, 3–4, and 3–7.

44 Okhotin, V. N., Titov, A. A., and Kashkakha, A. V., "Features of the Design Solutions for the Berezovskoye GRES No. 1," *Elektricheskiye stantsii*, no. 6 (1982): 20–28, esp. 24.

45 Novitskiy, N. V., Khromykh, G. I., and Lopayeva, N. P., "Thermal Characteristics of Ekibastuz Deposit Coal (Mine 5/6) as a Fuel for Large Block Power Stations," *Teploenergetika*, no. 12 (1972): 45–48, esp. 47–48.

46 Kuznetsov, N. V., Marshak, Yu. L., and Dik, E. P., "Main Directions of the Development of Steam Boilers for Kansk-Achinsk and Ekibastuz Coals," *Teploenergetika*, no. 5 (1981), pp. 7–13, esp. 8 and 10 (Kansk-Achinsk coal) and 11–12 (Ekibastuz coal).

47 Marshak, Yu. L., Protsaylo, M. Ya., Ivannikov, V. M., and Kucheryavyy, O. A., "Basic Problems of the Combustion of Kansk-Achinsk Basin Coals at Thermal Power Stations," *Elektricheskiye stantsii*, no. 1 (1981): 18–24, esp. 18.

48 Ovchar, V. G., Sotnikov, I. A., Ayzen, Kh. K., and Petrov, Ye. V., "Creation and

Improvement of Boiler Equipment for Effective Use of Ekibastuz Deposit Coals," *Teploenergetika*, no. 7 (1981): 5–8, esp. 5–6.

49 Kulikov, V. A., Pugach, L. I., and Yakushev, P. I., "Experience of Assimilating the Largest TES's of the Ural and Eastern Regions of the Country Using Ekibastuz Coal (Reftinsk, Yermakovo, Troitsk GRES's)," *Energetik*, no. 9 (1978): 8–9.

50 Sotnikov, I. A., Okerblom, Yu. I., Itman, D. L., Kharkin, Yu. A., and Marshak, Yu. L., "Principal Project and Design Solutions for the P-67 Steam Boiler Using Kansk-Achinsk Brown Coals for 800-MW Power Blocks," *Teploenergetika*, no. 8 (1978): 2–8, esp. 2.

51 Protsaylo, M., "On the Road to an Ocean of Energy," *Sotsialisticheskaya industriya* (November 19, 1977), p. 2.

52 Doroshchuk, V. Ye., and Rubin, V. B., eds., *Kotelnyye i turbinnyye ustanovki energoblokov moshchnostyu* 500 and 800 MVt. Sozdaniye i osvoyeniye (Boiler and Turbine Units for 500 and 800 MW Power Blocks: Creation and Assimilation) (Moscow: Izd. "Energiya," 1979), pp. 146–47 (P-67 boiler description) and 172–73 (P-57 boiler description).

53 Sotnikov, I. A., Ayzen, Kh. K., and Petrov, Ye. V., "Improvement of the Design of Type P-57 Steam Generators on the Basis of the Experience of Its Operation at the Troitsk GRES," *Teploenergetika*, no. 6 (1977): 2–5, esp. 2.

54 Shagalova, S. L., Malysheva, V. S., Chavchanidze, Ye. K., Parshikov, D. I., Sotnikov, I. A., Petrov, Ye. V., and Galuskin, V. B., "Analysis of the Operation of the Furnace Chamber and Fines Preparation of the P-57R Boiler for 500 MW Power Blocks Using Ekibastuz Coals," *Teploenergetika*, no. 3 (1983): 35–40.

55 Ayzen, Kh. K., Vasilyev, A. A., Vukolova, A. I., Ivanov, A. G., Petrov, Ye. V., Chakrygin, V. G., Chernigin, S. P., and Shchelokov, V. I., "Steam Generator for 800 MW Power Block Using Ekibastuz Coal," *Teploenergetika*, no. 6 (1977): 5–7.

56 Gantman, Ya., "Structural Changes in the Fuel Balance of the USSR," *Planovoye khozyaystvo*, no. 11 (1971): 88–91.

57 Filippov, B. S., "The Effectiveness of Transporting Kuznetsk Coals and Coke to the Center of the European Part of the USSR," *Koks i khimiya*, no. 3 (1977): 48–51, esp. 51.

58 Popov, V., and Bogachuk, A., "The Kuznetsk Variant," *Pravda* (August 25, 1978), p. 2.

59 "A Comprehensive Program of Work for the Construction of Main Coal Slurry Pipelines," *Stroitelstvo truboprovodov*, no. 11 (1978): 37.

60 Chalyy, G., *Energetika, vchera, sevodnya, zavtra* (Power Engineering Yesterday, Today, Tomorrow) (Kishinev: Izd. "Kartya Moldovenyaske," 1977), p. 147.

61 Fotin, V. P., "Development of a Complex of Equipment for the Transmission of Direct Current of 1500 kv from Ekibastuz to the Center," *Elektrotekhnika*, no. 6 (1978): 1–6, esp. 1.

62 Krapchin, I. P., "Role of Solid Fuel in the Fuel-Energy Economy and Problems of Coal Enrichment," *Khimiya tverdogo topliva*, no. 3 (1977): 4–10.

63 "Draft Main Directions of Economic and Social Development of the USSR for 1981–1985 and for the Period to 1990," *Izvestiya* (December 2, 1980), p. 3.

64 Lukin, V. I., "Enrichment of Coal," *Ugol*, no. 9 (1981): 22–24.

65 Report on trip to the Soviet Union by Miller, K. J., Goreff, B., and Smithson, G. R., Jr., of Battelle's Columbus Laboratories, Columbus, Ohio, March 24, 1976.

66 Sheyndlin, A., and Kalechits, I., "Gasoline from Coal," *Izvestiya* (April 24, 1981), p. 2.

67 Sheyndlin, A., "Pending the Experiment," *Sotsialisticheskaya industriya* (June 30, 1981), p. 2.

68 Altshuler, V. S., *Novyye protsessy gazifikatsii tverdogo topliva* (New Processes for Gasification of Solid Fuel) (Moscow: Izd. "Nedra," 1976), pp. 4, 15–21, 27, 56.

69 Krichko, A. A., "Problems of the Comprehensive Use of Coal," *Khimiya tverdogo topliva*, no. 6 (1977): 3–10, esp. 6.

70 Campbell, R. W., *Soviet Energy Technologies: Planning, Policy, Research and Development* (Bloomington: Indiana University Press, 1980), p. 176.

71 Palta, R. S., "Gasification of Moscow Coal by a Steam-Oxygen Blast Under Pressure," *Gazovaya promyshlennost*, no. 5 (1956): 10–13.

72 Krapchin, I. P., Korolkova, O. M., Lebedev, V. V., and Nikanorova, L. P., "Production of Methanol from Coal," *Khimiya tverdogo topliva*, no. 1 (1979): 137–42, esp. 137, 142.

73 Sechenov, G. P., "Production of a Power Gas from Sulfurous Coals of the Western Donbass by Their Gasification in a Fluidized Bed Under Pressure," *Khimiya tverdogo topliva*, no. 6 (1971): 59–66.

74 Novikov, L. Z., "Industrial Gasification of Central Asian Brown Coals in a Fluidized Bed With the Aim of Producing Synthetic Ammonia," *Khimicheskaya pererabotka topliva: Trudy II vsesoyuznogo soveshchaniya po iskusstvennomu zhidkomu toplivu i tekhnologicheskim gazam* (Chemical Processing of Fuels: Proceedings of the Second All-Union Conference on Synthetic Liquid Fuel and Industrial Gases) (Moscow: Izd. Akademii nauk SSSR, 1957), pp. 309–19, esp. 309.

75 Sechenov, G. P., and Altshuler, V. S., "Application of High Pressures in Fluidized-Bed Gas Generators," *Gazovaya promyshlennost*, no. 11 (1958): 12–18, esp. 12.

76 Sechenov, G. P., and Altshuler, V. S., "Gasification of Fine-Grain Fuel in a Fluidized Bed Under Pressures of Up to 15 Atm.," *Gazovaya promyshlennost*, no. 11 (1959): 14–18, esp. 14, 15.

77 Sechenov, G. P., and Altshuler, V. S., "Gasification of Krasnoyarsk Brown Coals in a Fluidized Bed at a Pressure of 20 Atm.," *Gazovaya promyshlennost*, no. 9 (1962): 15–20, esp. 20.

78 Altshuler, V. S., and Sechenov, G. P., "Gasification of Brown Coal in a Fluidized Bed Under Pressure with Production of Power Gases for Thermal Electric Stations," in V. S. Altshuler, ed., *Gazovyye protsessy* (Gas Processes) (Moscow: Izd. "Nauka," 1967), pp. 49–54.

79 Krichko, A. A., "Prospects for the Production of Synthetic Fuel from Coal," *Ugol*, no. 11 (1982): 35–36.

80 Krichko, A. A., and Chernenkov, I. I., "Present Status and Prospects for Development of Coal Gasification," *Ugol*, no. 8 (1978): 39–41.

81 Keneman, F. Ye., Kalyuzhnyy, V. V., Panov, V. I., Sokolov, Z. A., Erkin, L. I., and Nefedov, P. Y., "Processing of Brown Coals and Low-Caking Coals by Heat-

Contact Coking in a Fluidized Bed," United Nations, Economic Commission for Europe, Seminar on Technologies for the Utilization of Low-Calorie Fuels, Varna, Bulgaria, April 20–22, 1976, SC.TECH/SEM.5/R.16 (SUMMARY), March 9, 1976, pp. 12, 20.

82 "Present Problems of Processing Solid Fuels," *Trudy* (Moscow Chemical-Technical Institute imeni Mendeleyev), no. 91 (1976).

83 Krichko, A., "Results of the All-Union Conference on Chemistry and Technology of Synthetic Fuel," *Khimiya tverdogo topliva*, no. 6 (1980): 3–8.

84 Styrikovich, M. A., and Sheyndlin, A. Ye., "Conversion of Primary Energy," position paper for the Tenth World Energy Conversion Conference, Istanbul, Turkey, September 19–23, 1977.

85 "Prospects for the Use of Coal in the Production of Liquid and Gaseous Hydrocarbons," United Nations, Economic Commission for Europe, Group of Experts on the Utilization and Preparation of Solid Fuels, Sixth Session, June 16–18, 1975, COAL/GE.3R.13Add.2, April 3, 1975.

86 Tagliabue, J., "German Coal Plant Deal Expected with Soviet," *New York Times* (September 19, 1981), p. 29.

87 "In the Presidium of the USSR Supreme Soviet," *Sovetskaya Rossiya* (November 5, 1980), p. 2.

88 "In the Presidium of the USSR Supreme Soviet," *Sovetskaya Rossiya* (November 6, 1980), p. 2.

89 Jones, E. A., "Decision-Making on Energy Policy in the USSR: The Political Determinants of the Fuel and Energy Balance, 1976–1980," Department of Political Science, University of Michigan, Ann Arbor, January 14, 1981 (mimeographed).

90 Krichko, A. A., Galkina, A. A., Titova, T. A., and Pchelina, D. P., "Hydrogenation of Coal—Status and Prospects," *Khimiya tverdogo topliva*, no. 4 (1978): 53–63, esp. 53.

91 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1980, no. W1083, p. A11.

92 "Soviets Are Said to Ask West Germans to Join Siberian Coal Project," *Wall Street Journal* (April 26, 1983), p. 31.

93 Krichko, A., "Liquid Coal: Fantasy or Reality," *Rabochaya gazeta* (May 24, 1977), p. 2.

94 Krichko, A. A., Titova, T. A., Konyashina, R. A., Filippov, B. S., Nikiforova, T. S., and Bronovets, T. M., "Method of Catalytic Hydrogenation of Coal," Author Certificate No. 257,484 (August 14, 1968), as abstracted in *Otkrytiya, izobreteniya, promyshlennyye obraztsy, tovarnyye znaki*, no. 36 (1969): 24.

95 Krichko, A. A., "Hydrogenation of Solid Fuel," *Khimiya tverdogo topliva*, no. 2 (1971): 31–39, esp. 37, 38.

96 Karpov, V., "In the Future—Gasoline from Coal," *Stroitelnaya gazeta* (May 8, 1981), p. 2.

97 Krichko, A. A., Yulin, M. K., Muselevich, D. L., Ravikovich, T. M., and Skvortsov, D. V., "Joint Hydropurification of Distillate Fractions from Coal and Petroleum," *Khimiya tverdogo topliva*, no. 6 (1972): 70–74.

98 Tsedevsuren, Titova, T. A., and Dembovskaya, Ye. A., "Hydrogenation of Boyan-

Tegsk Coal of the Mongolian People's Republic," *Khimiya tverdogo topliva,* no. 6 (1981): 17–19.

99 Semenov, L. V., "On the Development of Synthetic Liquid Fuel Production," *Ugol,* no. 9 (1981): 20–22.

100 Gagarin, S. G., Krichko, A. A., and Yulin, M. K., "An Investigation of the Process of Hydropurification Using Methods of Mathematical Planning of Experiments," *Khimiya tverdogo topliva,* no. 1 (1975): 89–93, esp. 90–91.

101 Krichko, A. A., Yulin, M. K., Ravikovich, T. M., Skvortsov, D. V., Muselevich, D. L., and Zamanova, L. P., "Hydrocracking of Distillates Extracted from Coal," *Khimiya tverdogo topliva,* no. 4 (1973): 75–81.

102 Gagarin, S. G., Zamanova, L. P., Krichko, A. A., and Yulin, M. K., "A Mathematical Description of the Hydrocracking of Distillates from the Liquid-Phase Hydrogenation of Coal," *Khimiya tverdogo topliva,* no. 1 (1976): 94–99.

103 Francis, W., and Peters, M. C., *Fuels and Fuel Technology* (Oxford: Pergamon Press, 1980), 2nd ed., p. 137.

104 Panov, V. I., Keneman, F. Ye., Kazakov, Ye. I., Nikolayev, A. M., Kalyuzhnyy, V. V., "Brown Coal for High-Energy Fuel and Chemical Raw Materials," *Soviet Export,* no. 3 (1979): 36–37.

105 "Soviets Use South African Idea for Coal Factory Complex," *Coal Age* (June 1979), p. 25.

106 Chukhanov, Z. F., "General Principles of Energy Technology," United Nations, Economic Commission for Europe, Seminar on Technologies for the Utilization of Low-Calorie Fuels, Varna, Bulgaria, April 20–22, 1976, SC.TECH/SEM.5/R.12, March 4, 1976.

107 Panov, V. I., "Prospects for the Integrated Use in Power Technology of Low-Calorie (Low-Grade) Fuel in the USSR," United Nations, Economic Commission for Europe, Seminar on Technologies for the Utilization of Low-Calorie Fuels, Varna, Bulgaria, April 20–22, 1976, SC.TECH/SEM.5/R.15, March 9, 1976, pp. 1, 2.

108 Shcherbakov, A., "The Construction Site Needs Rhythm," *Izvestiya* (September 14, 1982), p. 2.

109 Luganskiy, Yu., "Precious Brown Coal," *Sotsialistcheskaya industriya* (December 10, 1977), p. 2. [Translated as JPRS 70,850, March 28, 1978, pp. 61–63.]

110 Keneman, F. Ye., Kalyuzhnyy, V. V., Panov, V. I., Sokolovyy, E. A., "Treatment of Brown and Weakly Caking Coals by Thermal Contact Coking in a Fluidized Bed," United Nations, Economic Commission for Europe, Seminar on Technologies for the Utilization of Low-Calorie Fuels, Varna, Bulgaria, April 20–22, 1976, SC.TECH./SEM.5/R.16, March 5, 1976, pp. 7, 20.

111 Bruyer, G., "The Most Important Task of the Complex," *Sotsialisticheskaya industriya* (December 8, 1978), p. 2.

112 Kirsanov, V. I., Smirnova, T. S., Krapchin, I. P., Markina, T. I., and Zverev, D. P., "Production of High-Calorie Power Fuel—Thermocoal from the Brown Coals of the Kansk-Achinsk Basin," *Khimiya tverdogo topliva,* no. 3 (1977): 139–43, esp. 140.

113 Gagarin, S. G., Smirnova, T. S., Markina, T. I., Kirsanov, V. I., and Slivinskaya, I. I., "Kinetics of Change in the Yield of Residual Volatiles During Thermal

Treatment of Irsha-Borodino Coal in Vortex Chambers," *Khimiya tverdogo topliva*, no. 1 (1979): 87–91, esp. 87.

114 Krichko, A. A., and Semenov, L. V., "New Directions in Chemical Processing of Kansk-Achinsk Basin Coals," *Ugol*, no. 12 (1975): 62–66, esp. 62, 63.

115 Bratchenko, B. F., *Energiya uglya* (The Energy of Coal) (Moscow: Izd. "Nedra," 1981), p. 23.

116 Kazakov, Ye. I., and Molchanova, I. V., "On the Carcinogenic Properties of the Liquid Products of Brown Coal Pyrolysis," *Khimiya tverdogo topliva*, no. 2 (1981): 66–69, esp. 67.

117 "New Forms of Transport," *Ekonomicheskaya gazeta*, no. 16 (1983): p. 2.

118 Olofinskiy, Ye., "Development of Progressive Types of Transport for Coal and Ore Concentrates," *Planovoye khozyaystvo*, no. 8 (1980): 89–96. [Translated as JPRS 76, 585, October 8, 1980, pp. 25–34, esp. 26, 27, 29.]

119 Ushakov, S. S., *Ekonomika transporta topliva i energii* (Economics of the Transport of Fuel and Energy) (Moscow: Izd. "Energiya," 1980), p. 153.

120 Olofinskiy, Ye., "On the Development of Pipeline Hydraulic Transport," *Planovoye khozyaystvo*, no. 8 (1983): 49–52, esp. 49.

121 Olofinskiy, Ye. P., "Problems of Hydromechanics of Pipeline Systems for Hydrotransport of Solid Materials," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 4 (1979): 29–36, esp. 29.

122 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1981, no. W1145, p. A10.

123 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1204, p. A10.

124 Parshintsev, A., *Selskaya zhizn* (May 15, 1983), p. 1. [Translated as JPRS-UEN-84-001, January 3, 1984, pp. 56–57.]

125 Georgiyev, D., "Pipeline for Coal," *Sotsialisticheskaya industriya* (September 12, 1980), p. 2.

126 Borisenko, T. M., and Vodyanitskiy, V. P., "Evaluation of the Possible Ways of Increasing the Economic Effectiveness of Systems for Long-Distance Hydrotransport of Coal," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 4 (1979): 37–46, esp. 37.

127 U.S. Central Intelligence Agency, "Central Siberian Brown Coal as a Potential Source of Power for European Russia," April 1980, pp. 4–5.

128 Kelly, W. J., and Shaffer, H. L., "Soviet Options for the Utilization of Siberian Coal," presented at the forty-fourth annual meeting of the Midwest Economics Association, Chicago, March 28, 1980.

129 Baybrut, V., "First Starts of the Pneumatic Transporter," *Gudok* (March 19, 1982), p. 4.

130 Lebanidze, G., "Start-up of Lilo-2," *Pravda* (December 31, 1980), p. 6.

131 "Basic Directions of Work on Creation of Pipeline Pneumatic Container Systems," *Stroitelstvo truboprovodov*, no. 1 (1981): 31–32.

132 Aleksandrov, A. M., Aglitskiy, V. Ye., Kovanov, P. V., Lurye, M. V., Polyanskaya, L. V., Topolyanskiy, Yu. A., and Tsimbler, Yu. A., *Konteynernyy truboprovodnyy pnevmotransport* (Container Pipeline Pneumotransport) (Moscow: Izd. "Mashinostroyeniye," 1979), p. 9.

133 Belousov, V. B., "Results of Industrial Experiments with Capsule Hydraulic Transport of Petroleum Materials by a Petroleum Product Pipeline," *Transport nefteproduktov i uglevodorodnogo syrya*, no. 3 (1980): 14–16.

134 "Freight Floats Underground," *Izvestiya* (March 11, 1978), p. 3.

135 "Pipeline Container Systems for Agriculture," *Stroitelstvo truboprovodov*, no. 10 (1980): 30–31.

136 Konyashina, R. A., "All-Union Conference on the Chemistry and Technology of Obtaining Liquid and Gaseous Fuel from Coal, Oil Shale, and Petroleum Residues," *Khimiya tverdogo topliva*, no. 1 (1980): 158–59.

137 "Scientific and Organizational Decisions of the Presidium of the USSR Academy of Sciences," *Vestnik Akademii nauk SSSR*, no. 10 (1980): 139–40.

6 Technologies to Improve the Efficiency of Energy Utilization

1 Troitskiy, A., "New Frontiers of Soviet Power Engineering," *Planovoye khozyaystvo*, no. 12, (1976): 20–28.

2 Baybakov, N. K., "On the State Five-Year Plan for the Development of the USSR National Economy in 1976–1980 and the State Plan for the Development of the USSR National Economy in 1977," *Izvestiya* (October 28, 1976), pp. 2–4.

3 Kelly, W. J., "Industrial Energy Conservation in the Soviet Union: Thermal Power Generation," paper presented at the forty-eighth annual conference of the Southern Economic Association, Washington, D.C., November 10, 1978.

4 Sheyndlin, A. Ye., "From Science to Production—for the Energy of the Future," *Izvestiya* (March 30, 1979), p. 3.

5 Sheyndlin, A. Ye., Jackson, W. D., Brzozowski, W. S., and Rietjens, L. H. Th., "Magnetohydrodynamic Power Generation," paper presented at the Tenth World Energy Conference, Istanbul, September 19–23, 1977.

6 Kuznetsova, R., "Plasma Will Replace the Turbine," *Pravda* (October 1, 1979), p. 1.

7 Ustimenko, B., "Work on MHD Power Stations Fueled with Coal," *Kazakhstanskaya pravda* (January 25, 1983), p. 3.

8 Ovcharenko, V. A., "Prospects for More Effective Utilization of Fuel through MHD," *Natural Resources Forum*, no. 1 (1976): 63–76.

9 Pishchikov, S., "The First-Born of MHD Power Engineering," *Moskovskaya pravda* (January 24, 1981), p. 2.

10 Blokhnin, A., "Power Created by a Plasma," *Izvestiya* (May 5, 1981), p. 1.

11 Mosin, I., "The Most Profitable Power," *Trud* (March 4, 1981), p. 4.

12 Gorodetskiy, V. "MHD Generator Gives Power," *Trud* (May 14, 1982), p. 4.

13 Nersesov, I. L., Sidorov, A. Ya., et al., "Earthquake Forecasting by Deep Electric Probing of the Earth's Crust With the 'Pamir-1' MHD Generator," *Doklady Akademii nauk SSSR*, no. 1 (1979): 55–58.

14 Kiryasov, V., "Dialog with the Deep," *Pravda* (May 19, 1982), p. 6.

15 Kirillin, V. A., and Sheyndlin, A. Ye., "Application of Magnetohydrodynamic Generators in Nuclear Power Engineering," *Izvestiya Akademii nauk SSSR, Seriya energetika i transport*, no. 5 (1977): 32–40.

16 Program of the Sixteenth Symposium on the Engineering Aspects of Magneto-

hydrodynamics, Pittsburgh, May 16–18, 1977 (attended by J. K. Thompson).

17 "Advances in Magnetohydrodynamic Power Generation," *Ekonomicheskaya gazeta*, no. 18 (1978): 13.

18 Sheyndlin, A., "Pending the Experiment," *Sotsialisticheskaya industriya* (June 30, 1981), p. 2.

19 Zhimerin, D. G., Kiselev, Yu. N., Mironov, E. A., Popov, V. A., and Sinkevich, O. A., "Some Technical Aspects of Gaseous Detonation," *Acta Astronautica* (New York/Oxford) 1, nos. 9–10 (1974): 1201–17.

20 Petrick, M., and Shumyatskiy, B. Ya., *Open-Cycle Magnetohydrodynamic Electrical Power Generation*, Argonne National Laboratory, Argonne, Ill., 1978.

21 Popkov, V. I., and Glebov, I. A., "Work of the Scientific Council of AN SSSR on Theoretical and Electrophysical Problems of Electric Power Engineering," *Izvestiya Akademii nauk SSSR, Seriya energetika i transport*, no. 5 (1975): 3–29.

22 Shumyatskiy, B. Ya. (obituary), *Moskovskaya pravda* (August 17, 1982), p. 4.

23 Volkov, Yu. M. (obituary), *Moskovskaya pravda* (September 18, 1982), p. 4.

24 Campbell, R. W., *Soviet Energy Technologies: Planning, Policy, Research and Development* (Bloomington: Indiana University Press, 1980), pp. 184–91.

25 Popkov, V. I., and Glebov, I. A., "The Work of the Scientific Council of the Academy of Sciences, USSR, on Theoretical and Electrophysical Problems of Electric Power Engineering," *Izvestiya Akademii nauk SSSR, Seriya energetika i transport* 13, no. 5 (1975): 3–29.

26 "Scientific Sessions of the Division of Physical-Technical Problems of Power Engineering of the Academy of Sciences, USSR, and the Consolidation of Plenary Sessions of the Scientific Councils," *Elektrichestvo*, no. 1 (1976): 89–91.

27 O'Toole, T., "U.S. Aids Soviets in Testing a Unique New Power Source," *Washington Post* (October 11, 1978), p. A17.

28 USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR v 1983 g.* (National Economy of the USSR in 1983) (Moscow: Izd. "Finansy i statistika," 1984), pp. 68–69, 151.

29 Peterson, L. L., "The Development of Power Systems," *Elektricheskiye stantsii*, no. 12 (1980): 63–66.

30 Amann, R., Cooper, J., and Davies, R., *The Technological Level of Soviet Industry* (New Haven: Yale University Press, 1977), pp. 199–224, esp. 205.

31 "On Reconstruction of the Volgograd-Donbass Direct-Current Power Transmission Lines," *Energetik*, no. 1 (1981): 37.

32 Nekrasov, A. M., and Pervukhin, M. G., eds., *Energetika SSSR v 1976–1980 godakh* (Power Engineering in the USSR in 1976–1980) (Moscow: Izd. "Energiya," 1977).

33 Borisov, Ye. I., "Power Engineering in the First Year of the Tenth Five-Year Plan and Tasks for 1977," *Teploenergetika*, no. 1 (1977): 2–3.

34 "The Development of Electric Power in 1978 and Tasks for 1979," *Elektricheskiye stantsii*, no. 1 (1979): 2–6.

35 "Energy Resources Development," *Pravda* (December 17, 1976), p. 2.

36 "Power Lines," *Soviet Business and Trade* 5, no. 9 (1976): 5–6.

37 "Ultrahigh Voltage," *Sotsialisticheskaya industriya* (October 13, 1973), p. 2.

38 Dienes, L., and Shabad, T., *The Soviet Energy System* (Washington, D.C.: V. H. Winston & Sons, 1979), pp. 118, 147–48.

39 Belikov, V., "Electrical Marathon," *Izvestiya* (April 10, 1981), p. 2.

40 Neporozhniy, P. S., ed., *Elektrifikatsiya SSSR (1967–1977 gg.)* (Electrification of the USSR (1967–1977)) (Moscow: Izd. "Energiya," 1977), pp. 260–61.

41 *Ekonomicheskaya gazeta*, no. 24 (1982): 16. [Translated as JPRS 81,465, August 5, 1982, p. 15.]

42 Krupenik, N., "Superroutes for Electricity," *Sotsialisticheskaya industriya* (December 21, 1979), p. 1. [Translated as JPRS 75,687, May 13, 1980, p. 10.]

43 "A Bridge to Tomorrow's Power Transmission Techniques," *Energoexport*, no. 19 (1984), pp. 10–12.

44 Markovich, A., "An Energy Bridge of Great Length," *Stroitelnaya gazeta* (December 31, 1980), p. 3.

45 "Ekibastuz-Center Transmission Line," *Izvestiya* (March 12, 1977), p. 2.

46 *Kazakhstanskaya pravda* (February 23, 1982), p. 1. [Translated as JPRS 81,147, June 28, 1982, p. 23.]

47 Slavin, V., "Innovations in High-Voltage Power Transmission Lines," *Krasnaya zvezda* (February 1, 1977), no. 26, p. 4.

48 Sergeyev, A., "KATEK: The Forecasts and the Present," *Tekhnika i nauka*, no. 1 (1977): 4–8.

49 Glukhovskiy, M., "Energy Bridges into the Future," *Pravda* (October 5, 1981), p. 3.

50 Photograph caption in *Leningradskaya pravda* (June 5, 1981), p. 2.

51 Photograph caption in *Pravda* (March 30, 1981), p. 7.

52 Golovin, A., "Tamed Lightning," *Sovetskaya Moldaviya* (July 22, 1981), p. 3.

53 Photograph caption in *Sovetskaya Rossiya* (August 6, 1980), p. 2.

54 "Report of the U.S.-USSR Coordinating Committee on Scientific and Technical Cooperation in the Field of Research, Design and Operation of EHV-UHV Transmissions," Moscow, April 15, 1976.

55 Fotin, V. P., "Tests of High-Voltage 1,150-Kilovolt AC Equipment and 1,500-Kilovolt DC Equipment," *Elektrotekhnika*, no. 2 (1976): 1–2.

56 Pchelin, M., "A River of Energy Will Start to Flow," *Stroitelnaya gazeta* (January 23, 1980), p. 3.

57 Fotin, V. P., "Development of a Complex of Equipment for the 1500-kv Ekibastuz-Center Direct-Current Power Transmission Line," *Elektrotekhnika*, no. 6 (1978): 1–6.

58 "Prospects for Cryogenic Superconducting Power Lines," *Izvestiya* (February 4, 1977), p. 4.

59 Sudakov, V., "High-Ampere Superconducting Underground Cables," *Pravda* (April 1, 1977), p. 6.

60 "On Nontraditional Means of Power Transmission by Low Cooling," *Elektrichestvo*, no. 4 (1971): 1–9.

61 "In Sight—A Storehouse of Energy," *Moskovskaya pravda* (July 21, 1979), p. 2.

62 Edeskuty, F. J., Hoffer, J. K., Keller, W. E., Maley, M. P., Taylor, R. D., and Baker, L. H., Jr., "A Technical Assessment of the U.S.-USSR Superconducting Power Transmission Line Exchange," Los Alamos Scientific Laboratory, September 1978.

63 Photograph caption, *Pravda* (July 19, 1979), p. 3.

64 "Superconductivity: Sensations Expected," *Soviet Union*, no. 8 (1979): 24–25.

65 Zhimerin, D. G., *Energetika: nastoyashcheye i budushcheye* (Power Engineering: The Present and the Future) (Moscow: Izd. "Znaniye," 1978), rear cover.

66 Levitov, V., and Long, H. M., "Report of the U.S.-USSR Coordinating Committee on Scientific and Technical Cooperation in the Field of Superconducting Power Transmission" (08-0207), to the U.S.-USSR Joint Committee on Energy, October 6, 1978.

67 Personal Communication of J. K. Thompson with a Soviet scientist during visit to Battelle's Columbus Laboratories, Columbus, Ohio, by the Soviet delegation to the Second International Cryogenic Materials Conference, August 10, 1977.

68 "Proceedings of the Second U.S.-USSR Symposium on Superconducting Power Transmission," held at Washington, D.C., April 9, 1974, ERDA 76-91.

69 Krushelnitskiy, Ye., and Muladzhanov, Sh., "Tests are Underway," *Moskovskaya pravda* (May 5, 1981), p. 3.

70 Timchenko, V., "The South-Ukrainian Power Complex," *Leningradskaya pravda* (March 10, 1981), p. 1. [Translated as JPRS 78,525, July 15, 1981, pp. 1–2.]

71 Nekrasov, A. M., "Electrification of the National Economy from the GOELRO Plan to Our Times," *Elektricheskiye stantsii*, no. 12 (1980): 40–44.

72 Borisova, S., "Stored Energy," *Krasnaya zvezda* (November 21, 1981), p. 3. [Translated as JPRS 80,468, April 1, 1982, pp. 4–6.]

73 Donskyy, D., "There Shall Be a Kanev Energy Giant," *Radyanska Ukrayina* (February 12, 1981), p. 7. [Translated as JPRS 77,858, April 17, 1981, pp. 1–3.]

74 Petrov, N., "The First, the Zagorskaya," *Pravda* (April 4, 1982), p. 2. [Translated as JPRS 81,147, June 28, 1982, pp. 12–16.]

75 Conversation with Elton Hall of Battelle's Columbus Laboratories, Columbus, Ohio, February 28, 1985.

76 Blokhnin, A., "A Waterfall that Creates Energy," *Izvestiya* (August 26, 1978), p. 3. [Translated as JPRS 72,006, October 6, 1978, pp. 24–25.]

77 Prashchitskiy, I., "The GES in the Earth's Crust," *Sotsialisticheskaya industriya* (February 7, 1980), p. 4. [JPRS translation available.]

78 Aksyutin, P. K., et al., *Energetika SSSR v 1981–1985 godakh* (Power Engineering in the USSR in 1981–1985) (Moscow: "Energoizdat," 1981, pp. 112, 171.

79 Shaytanov, V. Ya., "Some Problems of Organization of Construction of Pumped-Storage Power Generating Plants," *Energeticheskoye stroitelstvo*, no. 4 (1979): 28–31.

80 Shnyukas, D., and Borisova, S., "The Kayshyadoris Peak," *Pravda* (September 29, 1982), p. 1. [Translated as JPRS 82,316, November 24, 1982, pp. 16–17.]

81 Shmulson, B. D., "The Kiev Hydroaccumulating Electric Power Station," *Gidrotekhnicheskoye stroitelstvo*, no. 4 (1972): 3–5.

82 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1984, no. W1315, p. A7.

83 Akhmetov, R., "How Can One 'Store' Electricity?" *Sovetskaya Rossiya* (October 24, 1982), p. 2. [Translated as JPRS 82,715, January 24, 1983, pp. 34–35.]

84 Avdeyev, G. N., "The Zagorsk Hydroaccumulation Power Station," *Gidrotekhnicheskoye stroitelstvo*, no. 4 (1972): 5–7.

85 Avdeyev, G. N., and Sakharova, G. A., "The Kayshyadoris Pumped-Storage Electric Power Station," *Gidrotekhnicheskoye stroitelstvo*, no. 4 (1979): 2–6, esp. 5.

86 Kutateladze, S., Durdukov, A. B., and Psakhis, B., "Where Do Our Thermal Rivers Flow To?" *Pravda* (February 21, 1977), p. 2.

87 Bannyy, N. P., Fedotov, A. A., Shiryayev, P. A., and Roytburd, L. N., *Ekonomika chernoy metallurgii SSSR* (The Economics of Ferrous Metallurgy in the USSR) (Moscow: Izd. "Metallurgiya," 1978), p. 91.

88 Yegorichev, A. P., "Conference of Ferrous Metallurgy Power Engineers," *Stal*, no. 5 (1977): 471–72.

89 Kelly, W. J., Shaffer, H. L., and Spengler, T. P., "Trends in the Energy Efficiency of Open-Hearth Furnaces in the Soviet Union," paper presented at the forty-fifth annual meeting of the Midwest Economics Association, Louisville, Ky., April 1–4, 1981.

90 Grigoryev, I., "Economic Efficiency—The Main Feature of the New 'TU' Models," *Vozdushnyy transport* (November 17, 1981), p. 3.

91 Kelly, W. J., *Directory of Selected Production Facilities in the Soviet Union*, directory prepared by Battelle's Columbus Division, Columbus, Ohio, January 10, 1986, pp. 19, 60, 61.

92 Sychev, M., "New Diesel," *Sotsialisticheskaya industriya* (August 31, 1983), p. 2.

93 Kelly, W. J., "Effects of the Soviet Price Reform of 1967 on Energy Consumption," *Soviet Studies*, 30, no. 3 (July 1978): 394–402.

94 Tam, S. W., Blomquist, C. A., and Kartsounes, G. T., "Underground Pumped Hydro Storage—An Overview," *Energy Sources*, no. 4 (1979): 329–51, esp. 348–49.

7 Alternative Sources of Energy

1 Kolodin, M. V., and Shefter, Ya. I., "Wind Energetics," *Great Soviet Encyclopedia* (New York: Macmillan, 1974), vol. 4, pp. 701–3.

2 Sidorov, V., and Bogdashkin, P., "The Energy of the Azure Ocean," *Pravda* (July 18, 1976), p. 2.

3 Konovalov, B., "Wind and Solar Power Engineering," *Izvestiya* (November 21, 1972), p. 2.

4 Barkhatov, A., "The Wind Drives the Sea," *Moskovskiy komsomolets* (September 17, 1977), p. 4.

5 "Harnessing the 'Cyclone,'" *Pravda* (December 11, 1977), p. 3.

6 Ponomareva, G., "Harnessing the 'Cyclone,'" *Sovetskaya Rossiya* (June 16, 1977), p. 4.

7 Yegorov, Ye., "The Energy of the Wind," *Moskovskiy komsomolets* (September 25, 1981), p. 4.

8 "A Windmill for Northerners," *Sotsialisticheskaya industriya* (August 11, 1983), p. 2.

9 "Soviets Set Wind-Power Goal," *Christian Science Monitor* (April 26, 1978), pages unknown.

10 Kasyanov, Yu., "The Wind in Harness," *Izvestiya* (September 18, 1983), p. 1.

11 Alimov, K., "The Wind Giving Light," *Stroitelnaya gazeta* (October 7, 1980), p. 3.

12 Shefter, Ya., "Regenerative Energy Resources," *Tekhnika i vooruzheniye*, no. 12

(1976): 7.

13 Löf, George O. G., "Summary of Technical Discussions on Solar Energy Development in the Soviet Union," unpublished paper, no date [after October 1, 1972].

14 Kuznetsov, A., "I Believe: Sailing Vessels Will Return," *Rabochaya gazeta* (September 19, 1982), p. 4.

15 Kachikov, S., "Forward, To Sails," *Rabochaya gazeta* (January 14, 1979), p. 4.

16 "Transparus-82," *Rabochaya gazeta* (September 12, 1982), p. 2.

17 Kasatyy, S., "The Wind Gives Back Energy," *Gudok* (December 9, 1981), p. 4.

18 Grünbaum, R., "Alternative Energy Sources in the USSR," *Ambio*, no. 2 (1978): 49–55.

19 Pogosov, G., "Harnessing the Wind," *Vyshka* (February 19, 1978), p. 3.

20 "Utilizing the Power of the Wind," *Pravda* (May 16, 1977), p. 2.

21 Yermolayev, B., "An Electric Power Station for a Shepherd's Hut," *Trud* (December 11, 1981), p. 4.

22 Korneyev, V., "On the Seven Winds," *Izvestiya* (June 30, 1982), p. 3.

23 "Renewable Sources of Energy," *Ekonomicheskaya gazeta*, no. 23 (June 1983): 2.

24 "The Institute of Comprehensive Fuel and Energy Problems," *Planovoye khozyaystvo*, no. 2 (1975): 148–49.

25 Kuchushev, A., "Light Obtained from the Wind," *Trud* (June 28, 1980), p. 4. [Translated as JPRS 76,203, August 11, 1980, pp. 8–9.]

26 Useynova, I., "'Endless' Sources of Energy: When Will Their Time Come?" *Znaniye-sila*, no. 6 (1978): 14–18. [Translated as JPRS 71,771, August 29, 1978, pp. 7–19.]

27 Letter from NASA's Lewis Research Center to Richard E. Balzhiser, assistant director, Office of Science and Technology, reporting on trip to USSR by U.S. delegation, dated October 19, 1972.

28 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1978, no. W978, p. A15.

29 "They Catch the Wind," *Pravda* (June 7, 1982), p. 2.

30 Lidorenko, N. S., "Ecological Power Engineering," *Priroda*, no. 9 (1974): 9–17.

31 Sidorov, V. V., and Pavlov, V. K., "Wind Power in the Service of the National Economy," *Gazovaya promyshlennost*, no. 4 (1983): 20–23. [Translated as JPRS 83,870, July 12, 1983, pp. 59–65.]

32 Kelly, W. J., Shaffer, H. L., and Thompson, J. K., "The Economics of Nuclear Power in the Soviet Union," *Soviet Studies* 34, no. 1 (1982): 43–68.

33 Korneyev, V., "Wind, You Are Mighty," *Izvestiya* (February 1, 1981), p. 6.

34 USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR v 1983 g.* (National Economy of the USSR in 1983) (Moscow: Izd. "Finansy i statistika," 1984), pp. 150 (electrical capacity), 152 (shale, peat, firewood).

35 "Big Wind Turbine Planned," *Columbus Dispatch* (June 8, 1983), p. A8.

36 Vashkevich, K., Zhuravlev, P., and Shefter, Ya., "Money for the Wind?" *Pravda* (January 5, 1981), p. 3. [Translated as JPRS 77,938, April 27, 1981, pp. 1–4.]

37 Kryuchkov, V., and Sokolov, B., "Created, But Not Introduced. Why?" *Izvestiya* (July 20, 1983), p. 2.

38 "First of a Kind in Solar Power," *Krasnaya zvezda* (January 28, 1981), p. 1.

39 Itman, D. L., Biryukov, A. A., Kharkov, N. V., Lokshin, B. A., and Gladilin, V. I.,

"Construction of Experimental Solar Steam Generator of an Experimental Solar Electric Station with Power of 5 MW (SES-5)," *Geliotekhnika*, no. 1 (1983): 33–37.

40 Photograph caption, *Sotsialisticheskaya industriya* (September 15, 1983), p. 6.

41 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1242, p. A3.

42 Polyakov, A., "Plans for Solar Electric Power Plants," *Izvestiya* (April 6, 1980), p. 6.

43 Lobanov, I., "The Time of Large-Scale Solar Power Engineering," *Sovetskaya Kirgiziya* (November 23, 1982), p. 3.

44 Sergeyeva, I., "Solar Electric Power Station," *Pravda* (June 7, 1981), p. 1.

45 Salomatin, A., "Solar Megawatts," *Moskovskaya pravda* (July 20, 1980), p. 3.

46 "The Sun Works," *Sovetskaya Latviya* (February 7, 1981), p. 1.

47 Akhmedov, R. B., "Sun, Share Your Energy," *Pravda vostoka* (May 7, 1982), pp. 1–2.

48 "Solar Technology Without Exotic Elements," *Moscow News*, no. 3 (January 23–30, 1983): 10.

49 Ovechkin, F., "Plans for Solar and Fuel-Burning Power Plant," *Sovetskaya Kirgiziya* (June 29, 1983), p. 2.

50 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1242, pp. A4-A5.

51 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1983, no. W1220, p. A5.

52 Zorich, I., "Prospects for Power Generation From Space," *Nedelya*, no. 20 (1978): 11.

53 Konovalov, B., "Arrangement of the Orbiting Station 'Salyut-6,'" *Izvestiya* (December 14, 1977), p. 2.

54 Vanke, V. A., Lopukhin, V. M., and Savvin, V. L., "The Problems of Satellite Solar Power Stations," *Uspekhi fizicheskikh nauk* 123, no. 4 (1977): 633–55.

55 Zaytsev, Yu., "The Cosmos—Far and Near," *Pravda* (June 13, 1977), p. 4.

56 Vanke, V., "Feasibility of Solar Power Stations in Space," *Izvestiya* (February 25, 1983), p. 3.

57 Landsman, A. P., Strebkov, D. S., and Unishkov, V. A., "High Voltage Photoelectric Converter of Solar Energy," *Sbornik trudov Energeticheskogo instituta imeni G. M. Krzhizhanovskogo*, 1973, pp. 68–75.

58 Manilova, Zh., "Taming the Sun," *Leningradskaya pravda* (December 18, 1982), p. 2.

59 Shitov, V., "The Sun Is in the Hands of the Scientists," *Vozdushnyy transport*, (February 19, 1981), p. 4. [Translated as JPRS 78,020, May 7, 1981, pp. 6–7.]

60 Alferov, Zh., "Materials Science Advances Bring Commercial Solar Energy Closer," *Pravda*, (January 31, 1983), p. 7.

61 Tychinskaya, A., "Solar Institute Created," *Sovetskaya Estoniya* (January 5, 1979), p. 1.

62 "New Institute: Range of Research," *Turkmenskaya iskra*, (February 17, 1979), p. 4.

63 Grachev, A., "How Many Jobs Does the Sun Have?" *Pravda* (June 11, 1982), p. 6.

64 "The Sun in the Service of Power Engineering," *Ekonomicheskaya gazeta*, no. 46 (November 1982): 13.

65 Photograph caption, *Turkmenskaya iskra* (July 24, 1983), p. 4.

66 Solomenko, Ye., "The Rainbow in the Desert," *Pravda* (August 11, 1983), p. 3.

67 Babayev, N., "Solar Heating," *Stroitelnaya gazeta* (September 2, 1979), p. 3.

68 Mosin, I., "Serve People, Sun," *Trud* (May 8, 1980), p. 3.

69 "The Sun Works for Man," *Gudok* (December 27, 1979), p. 4.

70 "Solar Tracking System," *Stroitelnaya gazeta* (May 16, 1980), p. 3.

71 Blokhnin, A., "The Refueller Is the Sun," *Izvestiya* (October 6, 1983), p. 2.

72 Nesvitenko, N., "Electric-Power Stations Without Turbines," *Gudok* (July 7, 1981), p. 4. [Translated as JPRS 78,759, August 14, 1981, pp. 4–5.]

73 Shlyapnikova, L., "Science in the Higher School," *Turkmenskaya iskra* (June 5, 1981), p. 3.

74 Presnyakov, A., "In a Ring of Reflectors," *Sotsialisticheskaya industriya* (January 31, 1980), p. 4.

75 "Solar Power Engineering Present and Future," *Trud* (July 24, 1977), p. 4.

76 Fazylov, A., "Solar Factory," *Nedelya*, no. 1 (January 3–9, 1977): 4.

77 Blokhnin, A., "At the Focus of Solar Rays," *Izvestiya* (February 8, 1981), p. 3.

78 "The Sun Melts," *Sovetskaya Latviya* (August 13, 1982), p. 4.

79 Kankanyan, Yu., "Solar Power Facility to Have Furnace for Highly Pure Materials," *Sovetskaya Kirgiziya* (April 27, 1983), p. 4.

80 Danilovskiy, F., "Solar Collector," *Moskovskiy komsomolets* (July 22, 1982), p. 4.

81 Taksir, K., "At the Junction of Science and Production," *Sotsialisticheskaya industriya* (February 2, 1983), p. 2.

82 Semenov, N. N., "Utilization of Solar Energy: Development of Chemical and Biochemical Research," *Vestnik Akademii nauk SSSR*, no. 4 (1977): 11–22.

83 Yatrov, S., and Pyatkin, A., "Effectiveness of Utilization of Fuel-Energy Resources," *Planovoye khozyaystvo*, no. 2 (1979): 8–17.

84 Shchetinina, D., "Vice-President of Ukrainian Academy Assesses Solar Energy Prospects," *Vodnyy transport* (December 26, 1978), p. 3.

85 Askerov, A., "The Earth's Deep Heat and the Possibilities for Using It," *Bakinskiy rabochiy* (August 14, 1981), p. 3. [Translated as JPRS 79,258, October 21, 1981, pp. 18–20.]

86 Nurshanov, V. A., Sedykh, Yu. S., and Renne, V. G., "Deep Heat of the Earth," *Gazovaya promyshlennost*, no. 6 (1977): 19–21.

87 Simonovich, N., "Thermal Energy of the Planet," *Gudok* (January 11, 1975), p. 4.

88 Solovyenko, M. "The Heat of the Earth," *Komsomolskaya pravda* (December 20, 1979), p. 4.

89 Gadzhiyev, A., "Geothermal Power Engineering," *Ekonomicheskaya gazeta*, no. 29 (July 1977): 18.

90 Zinovyev, P., "The Heat of Kamchatka," *Pravda* (April 1, 1980), p. 3. [Translated as JPRS 75,941, June 26, 1980, pp. 26–29.]

91 Pushkar, A., "Work, Heat of the Earth," *Izvestiya* (January 12, 1978), p. 3.

92 Reference not cleared for release at this time.

93 Dvorov, I. M., *Geotermalnaya energetika* (Geothermal Power Engineering)

(Moscow: Izd. "Nauka," 1976), pp. 24–25, 67–68.

94 Useynova, I., "Geothermal Industry," *Sovetskaya Latviya* (August 26, 1977), p. 2.

95 "Underground Oceans of Energy," *Pravda* (June 20, 1978), p. 3.

96 "Geothermal Power Station in Stavropol," *Sotsialisticheskaya industriya* (February 24, 1982), p. 2. [Translated as JPRS 80,849, May 19, 1982, p. 28.]

97 Dvorov, I., "The Burning Energy of the Earth's Interior," *Pravda* (December 15, 1978), p. 3.

98 Dergachev, A., "Underground Heat Works," *Izvestiya* (October 3, 1981), p. 2. [Translated as JPRS 80,441, March 30, 1982, p. 49.]

99 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1981, no. W1149, pp. Ai, A11.

100 "Thermal Water Injection," *Trud*, (December 2, 1975), p. 1. [Translated as JPRS 66,582, January 14, 1976, p. 39.]

101 Yatrov, S. N., "Energy from the Bowels of the Earth," *Soviet Weekly* (December 9, 1978), p. 5.

102 Kirillin, V., "The Power Industry: Problems and Prospects," *Kommunist*, no. 1 (1975): 43–51.

103 Kelly, W. J., "Industrial Energy Conservation in the Soviet Union: Thermal Power Generation," paper presented at the forty-eighth annual conference of the Southern Economic Association, Washington, D.C., November 10, 1978.

104 Dienes, L., and Shabad, T., *The Soviet Energy System* (Washington, D.C.: V. H. Winston & Sons, 1979), pp. 124–26, 200–201.

105 "Towns and Ore Mines," *Pravda* (May 29, 1979), p. 2.

106 Gadzhiyev, A., "Pent-up Energy," *Pravda* (July 5, 1981), p. 3. [Translated as JPRS 78,900, September 3, 1981, pp. 36–39.]

107 USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR v 1979 g.* (National Economy of the USSR in 1979) (Moscow: Izd. "Statistika," 1980), pp. 146, 148, 170, 171.

108 USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR v 1974 g.* (National Economy of the USSR in 1974) (Moscow: Izd. "Statistika," 1975), p. 219.

109 Lavrov, N. V., and Kulakova, M. A., "Underground Gasification of Coal," *Bolshaya sovetskaya entsiklopediya* (Great Soviet Encyclopedia) (Moscow: Izd. "Sovetskaya Entsiklopediya," 1975), 3rd ed., vol. 20, pp. 110–11.

110 Arens, V. Zh., and Petrenko, Ye. V., "The Status and Prospects of Underground Gasification of Coal," *Ugol*, no. 5 (1981): 20–22.

111 Cadman, W. H., "Underground Gasification of Coal," *Reviews of Petroleum Technology* 7 (1947): 326–29.

112 Campbell, R. W., *The Economics of Soviet Oil and Gas* (Baltimore: Johns Hopkins University Press, 1968), pp. 8–9.

113 Reference not cleared for release at this time.

114 Zvyagintsev, K. N., "Underground Coal Gasification in the USSR," *Colliery Guardian*, no. 2 (1982): 65–68.

115 Chukhanov, Z. F., *Nekotoryye problemy topliva i energetiki* (Some Problems of Fuel and Power Engineering) (Moscow: Izd. Akademii Nauk SSSR, 1961), p. 301.

116 Lavrov, N. V., Nusinov, G. O., and Semenenko, D. K., "Some Results of an

Investigation of the Underground Gasification of Brown Coals," *Khimiya tverdogo topliva*, no. 1 (1968): 113–20.

117 Krichko, A. A., and Chernenkov, I. I., "Present Status and Prospects for Development of Coal Gasification," *Ugol*, no. 8 (1978): 39–41.

118 Altshuler, V. S., *Novyye protsessy gazifikatsii tverdogo topliva* (New Processes for Gasification of Solid Fuel) (Moscow: Izd. "Nedra," 1976), pp. 15–21.

119 Bratchenko, B. F., et al., *Ugolnaya promyshlennost SSSR, 1917–1967* (The Coal Industry of the USSR, 1917–1967) (Moscow: Izd. "Nedra," 1969), p. 8.

120 Reference not cleared for release at this time.

121 "Contemporary Scientific Investigations of the FRG and Belgium in the Field of Underground Gasification of Coal," *Ugol*, no. 11 (1976): 73.

122 Kreynin, Ye. V., Fedorov, N. A., Antonova, R. I., Volk, A. F., and Gershevich, E. G., "Method of Uniting Wells," Author Certificate No. 571,109 (June 12, 1974), as abstracted in *Otkrytiya, izobreteniya, promyshlennyye obraztsy, tovarnyye znaki*, no. 36 (1978): 200.

123 Gluzberg, Ye. I., "Heat and Mass Exchange in the Process of Spontaneous Heating of a Coal Seam," *Fizicheskiye protsessy gornogo proizvodstva*, no. 5 (1978): 66–70.

124 Kreynin, Ye. V., and Zvyagintsev, K. N., "Trends in the Production of Substitute Natural Gas by the Method of Underground Processing of Coals," *Khimiya tverdogo topliva*, no. 6 (1978): 93–96.

125 Kushniruk, V. A., Bartoshinskaya, Ye. S., and Byk, S. I., "Underground Gasification of Coals of the Lvov-Volynsk Basin," *Ugol Ukrainy*, no. 10 (1979): 5–6.

126 "Where Coal Is Burned Underground," *Rabochaya gazeta* (February 7, 1980), p. 2. [Translated as JPRS 75,396, March 28, 1980, p. 39.]

127 *Referativnyy zhurnal: gornoye delo* (Abstracts Journal: Mining), no. 2 (1982), items 2B633–2B637.

128 Lavrov, N. V., "On Underground Gasification of Coal," *Vestnik Akademii nauk SSSR*, no. 6 (1954): 62–63.

129 RSFSR Ministry of Communications, *Spisok abonentov Moskovskoy gorodskoy telefonnoy seti* (List of Subscribers of the Moscow City Telephone Network) (Moscow: Izdaniye Moskovskoy gorodskoy telefonnoy seti, 1958), part I, p. 82.

130 "TU Moves on Lignite, Uranium Programs," *Electrical World* (April 15, 1978), pp. 32–33.

131 "Texas Utilities Company Annual Report, 1979," March 1980, p. 16.

132 Lapedes, D. N., ed., *Encyclopedia of Energy* (New York: McGraw-Hill, 1976), pp. 535–36.

133 Chekalyuk, E., "Shale Awaits Its Master," *Pravda Ukrainy* (December 5, 1980), p. 2. [Translated as JPRS 77,477, February 27, 1981, pp. 26–27.]

134 Shelest, V. A., *Regionalnyye energoekonomicheskiye problemy SSSR* (Regional Energy Economic Problems of the USSR) (Moscow: Izd. "Nauka," 1975), p. 140.

135 "U.S.S.R. Mulls Changes in Oil Shale Operations," *Oil and Gas Journal* (September 5, 1983), p. 46.

136 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1981, no. W1146, p. A7.

137 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report),

1982, no. W1200, p. A11.

138 Semenov, A., "About the Value of Fuel Once More," *Sotsialisticheskaya industriya* (December 24, 1978), p. 2.

139 Panov, V. I., "Prospects for the Integrated Use in Power Technology of Low-Calorie (Low-Grade) Fuel in the USSR," United Nations, Economic Commission for Europe, Seminar on Technologies for the Utilization of Low-Calorie Fuels, Varna, Bulgaria, April 20–22, 1976, SC.TECH/SEM.5/R.15, March 9, 1976, pp. 1, 2.

140 Kala, K., and Vabar, M., *Electrification of the Estonian SSR* (Tallinn: "Periodika," 1979), p. 50.

141 Tyagunov, B. I., Smirnov, A. S., Chikul, V. I., Dolgopolov, B. M., and Iorudas, K. A., "Some Aspects of the Use of Low-Calorie Shales: Prevention of Air Pollution," United Nations Economic Commission for Europe, Seminar on Technologies for the Utilization of Low-Calorie Fuels, Varna, Bulgaria, April 20–22, 1976, SC.TECH/SEM.5/R.13, March 8, 1976, pp. 1–2.

142 Kelly, W. J., Shaffer, H. L., and Spengler, T. P., "Coal and Oil Shale R&D in the Soviet Union," prepared by Battelle's Columbus Laboratories, Columbus, Ohio, for Lawrence Livermore National Laboratory, Livermore, Calif., November 30, 1981, pp. 73–84.

143 U.S. Office of Technology Assessment, *An Assessment of Oil Shale Technologies* (Washington, D.C.: U.S. Government Printing Office, June 1980), pp. 105–12, 137–39, 516 (pyrolysis).

144 "The 60th Anniversary of the Great October Socialist Revolution," *Khimiya tverdogo topliva*, no. 5 (1977): 3–8.

145 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1982, no. W1198, p. A8.

146 Yefimov, V. M., and Rooks, I. Kh., "On the 50th Anniversary of the Processing of Kukersite Shale in Gas Generators," *Khimiya tverdogo topliva*, no. 5 (1974): 86–91.

147 Serebryannikov, N. D., "On the Processing of Shale at Kohtla-Jarve," *Khimiya tverdogo topliva*, no. 4 (1978): 20–21.

148 Altshuler, V. S., *Novyye protsessy gazifikatsii tverdogo topliva* (New Processes for Gasification of Solid Fuel) (Moscow: Izd. "Nedra," 1976), pp. 4, 15–21, 27, 56.

149 Petukhov, Ye. F., "The Status and Immediate Tasks of Shale Processing," *Neftepererabotka i neftekhimiya*, no. 10 (1977): 63—66.

150 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1982, no. W1168, p. A8.

151 Rooks, I., "Weighing the Prospects of the Oil-Shale Chemical Industry," *Rahva Haal* (July 10, 1981), p. 2. [Translated as JPRS 79,258, October 21, 1981, pp. 23–25.]

152 Aarna, A., "How Rich Are We? The Scientific-Technical Program of Comprehensive Oil-Shale Usage," *Rahva Haal* (February 20, 1982), p. 2. [Translated as JPRS 81, 109, June 23, 1982, pp. 12–16.]

153 Galynker, I. S., Tyagunov, B. I., Chikul, V. I., and Tyanav, I. V., "Results of Trials of a Test Industrial Unit for Thermal Processing of Shale with a Solid Heat-Carrier

at the 'Kiviyli' Shale Chemical Combine," *Energotekhnologicheskoye ispolzovaniye topliva* (Moscow: Izd. AN SSSR, 1963), no. 4, pp. 3–20.

154 Krichko, A. A., "Research in the Area of the Processing of Baltic Oil Shales and Shale Oils," *Trudy Instituta goryuchikh iskopayemykh*, vol. 12, *Khimiya i tekhnologiya topliva* (Moscow: Izd. AN SSSR, 1961), pp. 143–50.

155 Roginskiy, M., "New Products from Shales," *Leningradskaya pravda* (July 12, 1977), p. 1.

156 Orlov, V., "In the Arsenal of Power Engineering," *Leningradskaya pravda* (July 12, 1977), p. 1. [Translated as JPRS 69,909, October 4, 1977, pp. 9–11.]

157 *BBC Summary of World Broadcasts*, part 1: The USSR (Weekly Economic Report), 1980, no. W1083, p. A13.

158 Dyakova, M. K., "Production of Synthetic Liquid Fuel and Chemical Products by Means of the Thermal Solution of Solid Fuels," *Khimicheskaya pererabotka topliva: Trudy II Vsesoyuznogo soveshchaniya po iskusstvennomu zhidkomu toplivu i tekhnologicheskim gazam* (Chemical Processing of Fuel: Proceedings of the Second All-Union Conference on Synthetic Liquid Fuel and Industrial Gases) (Moscow: Izd. Akademii Nauk SSSR, 1957), pp. 261–75.

159 Vol-Epshteyn, A. B., Shpilberg, M. B., and Bregadze, T. A., "Thermal Solution of Baltic Oil Shales in a Flow-Through Unit," *Khimiya tverdogo topliva*, no. 2 (1980): 67–70.

160 Gorlin, M., and Yampolskiy, A., "Basic Directions in the Use of Peat Resources in the USSR," *Planovoye khozyaystvo*, no. 3 (1975): 123–29.

161 Deyev, L. V., and Kozlov, Yu. A., "A Study of the Process of the Combustion of Cut Peat in the Boiler of a Steam Generator," *Trudy Moskovskogo energeticheskogo instituta*, no. 213 (1975): 53–58.

162 Sokolov, B. N., "Peat Industry on the 60th Anniversary of the USSR's Formation," *Torfyannaya promyshlennost*, no. 12 (1982): 2–4. [Translated as JPRS 83,489, May 18, 1983, pp. 5–7.]

163 Opman, Ya., "Dust Has Become Fuel," *Sovetskaya Belorussiya* (September 23, 1982), p. 2. [Translated as JPRS 82,308, November 23, 1982, pp. 15–16.]

164 Danilov, R., "Hydrogen Is Working," *Izvestiya* (February 24, 1977), p. 6.

165 Akhmetov, R., "Fuel of the Future," *Moskovskaya pravda* (July 15, 1977), p. 3. [JPRS translation available.]

166 Bakirov, M., "A Treasure House of Beam Energy," *Vyshka* (September 12, 1979), p. 2.

167 Arutyunyan, V., "Hydrogen Power Engineering," *Kommunist* (June 11, 1982), p. 4.

168 Rustamov, M., "Hydrogen—An Ecologically Pure Energy Source," *Vyshka* (March 11, 1983), p. 3.

169 Andreyev, I., "The Fuel of the Future," *Leningradskaya pravda* (July 23, 1978), p. 2. [Translated as JPRS 71,797, September 1, 1978, pp. 51–54.]

170 Legasov, V. A., ed., *Atomnovodorodnaya energetika i tekhnologiya* (Nuclear-Hydrogen Energy and Technology), part 1 (Moscow: Atomizdat, 1978).

171 Bochin, V. P., Fridman, A. A., Legasov, V. A., Rusanov, V. D., and Sholin, G. V., "Hydrogen Production in Non-Equilibrium Plasmochemical Systems," *Hydrogen Energy System* (Proceedings of the Second World Hydrogen Energy Conference, Zurich, August 21–24, 1978), vol. 3, pp. 1183–1208.

172 Belousov, I. G., Legasov, V. A., and Rusanov, V. D., "Plasmochemical Cycle of Hydrogen Production from Water," *Hydrogen Energy System* (Proceedings of the Second World Hydrogen Energy Conference, Zurich, August 21–24, 1978), vol. 3, pp. 1169–81.

173 Borodin, A., "Metabolism and the Engines of the Future," *Vozdushnyy transport* (April 1, 1978), p. 3.

174 Chamara, V., "Energy Given by the Sun," *Pravda Ukrainy* (August 16, 1978), p. 4.

175 Narimanov, A., "Bacteria—Substitutes for Petroleum," *Leninskoye znamya* (July 19, 1981), p. 4.

176 Shashkov, A., "Expensive, but Profitable," *Sovetskaya Belorussiya* (April 9, 1982), p. 2.

177 Shabelskiy, O., "Hydrogen Instead of Gasoline?" *Trud* (December 14, 1978), p. 4.

178 Volnov, V., "The Engine of the 21st Century," *Trud* (October 20, 1984), p. 3.

179 *Alfa Catalogue: Research Chemicals and Materials, 1983–84* (Danvers, Mass.: Morton Thiokol, Alfa Products, June 1983), p. Y-43.

180 "Groundwork for a Hydrogen-Fueled Economy," *Business Week* (September 4, 1978), pp. 36B, 36F.

181 Struminskiy, V., "The Fuel of the Future—Hydrogen," *Pravda* (August 3, 1974), p. 3.

182 "The Fuel of the Future," *Kazakhstanskaya pravda* (July 16, 1975), p. 4.

183 Struminskiy, V., "A Promising Source of Energy," *Gudok* (May 7, 1981), p. 4.

184 "Transport of Liquid Hydrogen," *Sotsialisticheskaya industriya* (December 6, 1979), p. 4.

185 Sasorov, D., "The Future Is Up to Science," *Kazakhstanskaya pravda* (December 19, 1980), p. 4.

186 Andreyev, I., "Soviet Energy Expert Foresees the Hydrogen Revolution," *Soviet Weekly* (January 7, 1978), page unknown.

187 Andreyev, I., "The Fuel of the Future," *Sovetskaya Latviya* (July 2, 1978), p. 2. [JPRS translation available.]

188 Shpilrayn, E. E., and Malyshenko, S. P., "Certain Aspects of the Development of Hydrogen Power Engineering and Technology," *Teploenergetika* no. 8 (1980): 8–12, esp. 9.

189 "Hydrogen in Place of Gasoline," *Vechernyaya Moskva* (February 27, 1976), p. 4.

190 Alova, G., "Bounteous Genie from FIAN's Bottle," *Sotsialisticheskaya industriya* (May 15, 1980), p. 6.

8 Energy Modeling

1 "Dialectical Materialism," *Sovetskaya voyennaya entsiklopediya* (The Soviet Military Encyclopedia), vol. 3 (Moscow: Voyennoye Izd., 1977), pp. 173–76.

2 Graham, Loren R., *Science and Philosophy in the Soviet Union* (New York: Vintage Books, 1974), p. 327.

3 Melentyev, L. A., *Systemnyye issledovaniya v energetike* (Systems Research in Power Engineering) (Moscow: Izd. "Nauka," 1979), p. 10.

4 Makarov, A. A. and Vigdorchik, A. G., *Toplivno-energeticheskiy kompleks* (Fuel

and Energy Complex) (Moscow: Izd. "Nauka," 1979), pp. 12–14.

5 Venikov, V. A., ed., *O metodakh modelirovaniya pri izuchenii energeticheskikh sistem* (On Methods of Modeling During the Study of Energy Systems) (Moscow: Izd. Akademii nauk SSSR, 1963).

6 Belyayev, L. S., Kononov, Yu. D., and Makarov, A. A., "Methods and Models for Optimization of Energy Systems: Soviet Experience," Siberian Power Engineering Institute, Irkutsk, unpublished paper, 1977.

7 Kuznetsov, Yu. A., Merenkov, A. P., Melentyev, L. A., and Nekrasov, A. S., "Determining the Optimal Structure of the Long-Range Energy Balance with the Use of Computers," *Teploenergetika*, no. 5 (1962): 3–10.

8 "MELENTYEV Lev Aleksandrovich," *Bolshaya Sovetskaya Entsiklopediya* (Great Soviet Encyclopedia) (Moscow: Izd. "Sovetskaya entsiklopediya," 1974), vol. 16, p. 42.

9 Makarov, A. A., and Melentyev, L. A., "Problems of and Ways to Develop Power Engineering in the USSR," *Ekonomika i organizatsiya promyshlennogo proizvodstva*, no. 3 (1981): 17–45, esp. 17.

10 Makarov, A. A., "A Mathematical Model for Planning the Development of the Fuel and Energy Economy of the USSR," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 3 (1964): 295–300.

11 Melentyev, L. A., "Some Problems in the Theory of Optimization of the Energy Balance of the USSR," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 3 (1964): 275–82.

12 Makarov, A. A., "Mathematical Modeling of the Fuel and Energy Economy," *Ekonomika i matematicheskiye metody*, no. 6 (1967): 802–10.

13 Melentyev, L. A., "On the Problem of Optimization of Complex Economic Systems," *Ekonomika i matematicheskiye metody*, no. 4 (1967): 500–508.

14 Gershenzon, M. A., "Intersectoral Models for Long-Term Energy Forecasting," Siberian Power Engineering Institute, Irkutsk, unpublished paper, 1977.

15 Akhmedov, R. B., "Methodological Problems of Evaluating the Effectiveness of Utilization of Fuel and Energy Resources," paper for the Soviet-American Commission on Cooperation in the Area of Power Engineering, Working Group on Information in Energy, Moscow, 1977, pp. 6–7.

16 Vigdorchik, A., Kononov, Yu., Makarov, A., and Khazanov, M., "Methods of Optimization of Long-Range Development of the Fuel and Energy Complex of the USSR," *Planovoye khozyaystvo*, no. 2 (1975): 29–37.

17 Melentyev, L. A., and Makarov, A. A., "Features of the Optimization of the Development of the Fuel and Energy Complex," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 3 (1974): 12–19.

18 USSR Central Statistical Administration, *Narodnoye khozyaystvo SSSR, 1922–1982* (National Economy of the USSR, 1922–1982) (Moscow: Izd. "Finansy i statistika," 1982), p. 183.

19 Makarov, A. A., "Systems Research on the Long-Range Structure of the USSR's Fuel and Energy Comlex," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 3 (1980): 21–30.

20 Shatylov, N. F., and Gershenzon, M. A., *Metodologicheskiye polozheniya po ispolzovaniyu dinamicheskoy modeli mezhotraslevogo balansa v svodnom*

perspektivnom planirovanii (Methodological Positions on the Use of a Dynamic Model of Interbranch Balance in Summary Long-range Planning) (Novosibirsk: Izd. "Nauka," 1971). Cited in reference (10) to this chapter.

21 Makarov, A. A., Makarova, A. S., Vigdorchik, A. G., Zeyliger, A. N., Levental, G. B., and Belostotskiy, A. M., "The Role of Nuclear Power in the Long-Term Fuel-Energy Complex of the USSR," *Atomnaya energiya* 32, no. 3 (1972): 187–96.

22 Makarov, A. A., Makarova, A. S., and Zeyliger, A. N., "Investigation of the Indeterminancy Zone of Optimal Development of Complex Economic Systems," *Ekonomika i matematicheskiye metody*, no. 6 (1970): 849–63.

23 Koryakin, Yu. I., Baturov, B. B., Belostotskiy, A. M., Bobolovich, V. N., Levental, G. B., Lokshin, V. L., Smirnov, V. G., Chernavskiy, S. Ya., Barabanov, V. I., and Shkrabal, Y., "Mathematical Modeling of the Development of Nuclear Power," *Atomnaya energiya* 36, no. 6 (1974): 458–62.

24 Makarov, A. A., "The Role of Siberia in the Fuel and Energy Complex of the Country (Methods and Some Research Results)," *Ekonomika i matematicheskiye metody*, no. 5 (1979): 863–74.

25 Tkachenko, G. Ye., "On One Approach to the Evaluation of the Influence of Rates and Proportions of the Development of the National Economy on Long-Range Development of Energetics," in *Problemy optimalnogo otraslevogo planirovaniya* (Problems of Optimal Branch Planning) (Novosibirsk, IEIOPP AN SSSR, 1976). Cited in reference (14) to this chapter.

26 Golovin, A. P., Kitaygorodskiy, V. I., and Faynshteyn, I. Ya., "Forecasting the Reserves and Optimization of Regional Levels of Gas Extraction within the Framework of the Fuel-Energy Complex," *Ekonomika i matematicheskiye metody*, no. 5 (1979): 940–50.

27 Popyrin, L. S., *Matematicheskoye modelirovaniye i optimizatsiya teploenergeticheskikh ustanovok* (Mathematical Modeling and Optimization of Thermal Energy Equipment) (Moscow: Izd. "Energiya," 1978).

28 Tuchinskiy, M. P., and Rodnykh, Yu. V., *Matematicheskoye modelirovaniye: optimizatsiya piroliznykh ustanovok* (Mathematical Modeling and Optimization of Pyrolysis Equipment) (Moscow: Izd. "Khimiya," 1979).

29 Kurbatov, D. K., and Orlov, V. V., "Mathematical Modeling of Power Thermonuclear Stations with Hybrid Reactors," *Atomnaya energiya* 52, no. 6 (1982): 372–74.

30 Klyemin, A. I., Peskov, R. A., Frolov, E. V., "Structural Mathematical Model of the Reliability of an NPS: Method of Calculation," *Atomnaya energiya* 51, no. 4 (1981): 211–15.

31 Chaban, V. I., and Pavlyna, V. F., "Mathematical Model of a Saturated Salient-Pole Synchronous Machine," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 2 (1981): 72–81.

32 Belyayev, L. S., Gorskiy, Yu. M., Krumm, L. A., Makarov, A. A., Merenkov, A. P., Popyrin, L. S., Rudenko, Yu. N., and Sher, I. A., "Optimization and Management of Large Energy Systems," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 3 (1980): 31–46, esp. 32.

33 "The Institute of Comprehensive Fuel and Energy Problems," *Planovoye khozyaystvo*, no. 2 (1975): 148–49.

34 Belyayev, L. S., and Rudenko, Yu. N., *Sistemnyy podkhod pri upravlenii razvitiyem elektroenergetiki* (System Approach to the Management of the Development of Electric Power Engineering) (Novosibirsk: Izd. "Nauka," 1980).

35 Yu. M. Gorskiy, *Informatsionnyye aspekty upravleniya i modelirovaniya* (Informational Aspects of Management and Modeling) (Moscow: Izd. "Nauka," 1978).

36 A. A. Makarov, *Metody i modeli soglasovaniya iyerarkhicheskikh resheniy* (Methods and Models of Correlating Hierarchical Solutions) (Novosibirsk: Izd. "Nauka," 1979).

37 Voropay, N. I., *Uproshcheniye matematicheskikh modeley dinamiki elektroenergeticheskikh sistem* (Simplifying Mathematical Models of the Dynamics of Electrical Power Systems) (Novosibirsk: Izd. "Nauka," 1981).

38 Belyayev, L. S., *Resheniye slozhnykh optimizatsionnykh zadach v usloviyakh neopredelennosti* (Complex Optimization Problems in Conditions of Indeterminacy) (Novosibirsk: Izd. "Nauka," 1978).

39 Krumm, L. A., *Metody optimizatsii pri upravlenii elektroenergeticheskimi sistemami* (Methods of Optimization of Management of Electrical Power Systems) (Novosibirsk: Izd. "Nauka," 1981).

40 Kuznetsov, Yu. A. and Lemanovich, G. Ya., "Optimization of the Parameters of Main Gas Pipelines," *Izvestiya Akademii nauk SSSR, seriya energetika i transport*, no. 4 (1981): 14–19.

41 "New Scientific Institution of the Ukraine," *Pravda Ukrainy* (January 24, 1981), p. 3.

42 Green, D. W., and Higgins, C. I., *SOVMOD I, A Macroeconometric Model of the Soviet Union* (New York: Academic Press, 1977).

43 Campbell, R. W., *Trends in the Soviet Oil and Gas Industry* (Baltimore: Resources for the Future, Inc./Johns Hopkins University Press, 1976), p. 2.

44 Comment by Mason Soule, Department of Geography, The Ohio State University, Columbus, to the author, February 8, 1985.

45 Troitskiy, A., "Electric Power Engineering: Problems and Prospects," *Planovoye khozyaystvo*, no. 2 (1979): 18–25, esp. 20.

46 Jones, E. A., "Decision-Making on Energy Policy in the USSR: The Political Determinants of the Fuel and Energy Balance, 1976–1980," Department of Political Science, University of Michigan, Ann Arbor, January 14, 1981 (mimeographed).

47 Kelly, W. J., Shaffer, H. L., and Spengler, T. P., "Coal and Oil Shale R&D in the Soviet Union," report by Battelle's Columbus Laboratories, Columbus, Ohio, to Lawrence Livermore National Laboratory, Livermore, Calif., November 30, 1981.

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With a few exceptions, all Soviet organizations involved with energy policy-making, management, and R&D mentioned in the text and appendixes are listed in this index. Scientific councils and organizations engaged in the extraction and processing of fuels and the generation of electricity and other production activities are listed in the subject index under the appropriate subject (e.g., ferrous metals plants are listed under "Ferrous metallurgy: plants"). References to non-Soviet organizations also are provided in the subject index. Institutes having names beginning with "All-Union" are alphabetically arranged *within* the "All-Union" grouping by the first technically substantive word in the institute name. In order to save space, "Scientific Research Institute" has been abbreviated as "SRI" and "Institute," when standing alone, as "Inst."

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